

*Some Developments in  
Research in Science and  
Mathematics in  
Sub-Saharan Africa:  
Access, Relevance, Learning,  
Curriculum Research*

Edited by Lorna Holtman, Cyril Julie, Øyvind Mikalsen,  
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# *Foreword*

This book comprises a collection of articles of some research directions in sub-Saharan Africa. The contributors were, at the time of writing, primarily doctoral students involved in a research capacity development project, the GRADuate Studies in Science, Mathematics and Technology Education (GRASSMATE) project. GRASSMATE was launched in 2002 and funded for a five-year period by the Norwegian development agency, NUFU. The precursor of GRASSMATE project was the Postgraduate Programme in Mathematics Education. This project is reflected upon by Julie, Mikalsen and Persens (2005). It was towards the completion of the last-mentioned project that a survey was conducted in universities in sub-Saharan countries to ascertain the needs and interests for a doctoral education in Science and Mathematics Education. Responses came from most of the invited institutions and interests in pursuing doctoral studies were expressed by more than 50 non-doctoral-holding lecturers at the solicited universities in the sub-Saharan region.

Following consultation with the host institutions, 27 prospective students from Zimbabwe, Uganda, Swaziland, South Africa, Namibia, Malawi and Lesotho were invited to a seminar at the University of the Western Cape. This seminar was followed by further sessions of discussions on the readiness of the invited students to engage in doctoral studies. The outcome of these deliberations led to the selection of 21 students to pursue doctoral studies in Science, Mathematics and Technology Education. A further student, involved in Nursing Education, was selected to enter for a Master's degree with the intention to continue immediately with doctoral studies after the successful completion of the Master's degree. There was an equal split of female and male students.

Supervisors from universities in Norway, South Africa, Tanzania, Uganda and Zimbabwe guided the students and formed the backbone of the academic staff of the project. The project, being North–South and South–South collaboration, was anchored in Norway at the University of Bergen. Four professors and two associate professors from four higher education institutions in Norway (University of Bergen, University of Oslo, University of Agder and the University College of Volda) participated as supervisors. The anchoring institution in the South was the University of the Western Cape. Five professors and three senior lecturers from higher education institutions (University of

the Western Cape, University of Zimbabwe, University of Dar-es-Salaam and Makerere University) comprised the supervisory team members from sub-Saharan Africa.

As already mentioned, the project was primarily funded by the Norwegian development agency, NUFU. Additional funding was also received from the University of Bergen, and the University of the Western Cape provided infrastructural and other operational support.

The majority of the chapters in this book were primarily written by students. The supervisors supported them through commenting on drafts and sharpening their writing. The chapters were written when the project was about mid-way through the funding period of GRASSMATE and they deal with the research projects the students were pursuing.

## **Reference**

Julie, C., Mikalsen, O. and Persens, J. (2005). The 'complex reality' of research capacity development in mathematics education in southern African development community countries. *International Journal of Educational Research* 25, 591–601.

Øyvind Mikalsen and Cyril Julie

# *Introduction*

The different chapters in this collection should be read around the notions of access, adoption, adaptation and localisation.

Currently much attention in late developing countries is accorded to the provision of access to studies which will allow the pool of young people graduating from schools to enter science- and technology-related careers. This is driven by the belief that more school graduates entering these fields would substantially contribute towards the developmental needs of these countries. But access into institutions of higher learning only provides institutional access. A concern is that such students normally come from schooling environments suffering from a lack of resources – human, physical and financial. There is thus a need to provide such students with epistemological access to the disciplines of import to improve their chances of success. Some of the chapters deal with research related to epistemological access.

Research in any discipline does not occur in a vacuum. For any research endeavour there are antecedent studies on the topic of interest. A feature of studies of research in Science, Mathematics and Technology Education is that it is highly localised in terms of its empirical bases. This implies that although results have the potential to be generalised to a larger population of interest, it is problematic to universalise such generalisations. In environments where research productivity is low, it is not uncommon to find that there is either adoption, adaptation or localisation or some combination of these constructs of the problems being investigated, of the methods employed to address research problems, and the theoretical frameworks used in the research process. The value of such replication or quasi-replication studies is that they contribute towards knowledge production in the sense that they might provide more cases towards the universalisation of research results or provide a case which refutes assumed universality. As is evident, the three constructs are difficult to separate, but in reading the chapters it is possible to find the pivoting one which guides the chapter.

This introduction purposefully doesn't characterise the specific chapters under the four guiding constructs of the book. This is done so as to allow readers to use their own insight to decide the goodness-of-fit to the offered constructs. The book is divided into four sections or themes namely: Research; Access; Curriculum, Instruction and

Assessment and Relevance. The ideas of access, adoption, adaptation and localisation come through in these themes.

Cyril Julie and Lorna Holtman

# *Theme: Research*

Any research study requires that appropriate methods be sought to address the research object being pursued. Inspiration for such methods is found in the existing literature and includes data collection instruments, analysis methods and general approaches to the research endeavour. Notwithstanding their ready availability, these instruments, analysis methods and approaches are not like items on a shelf in, say a supermarket, to be collected and used as per the instructions. Researchers normally find that unchanged adoption brings its own set of problems requiring the need to adapt and localise instruments, analysis techniques and approaches. The chapters in this section deal with this issue.

Kapenda *et al.* describe the process of constructing a viable observation instrument to ascertain the extent to which learner-centred approaches manifest themselves in Namibian classrooms. The limitations and various versions of the instrument are presented to demonstrate how adaptations were made to an existing instrument to arrive at one that had the potential for utilisation in the proposed study.

The introduction of new content in school mathematics normally follows the process where the need for such content is motivated by experts – mathematicians, mathematics educators and mathematics curriculum developers. Once such motivations are found convincing, the content is elementarised and inserted into the curriculum with the necessary elementarised learning resource material. Inspired by the phenomenological approaches developed by the Dutch Realistic Mathematics Education School, Whittles *et al.* challenge this way of introducing new content. It is shown that new content has historical antecedents that need to be taken into account for new content to be inserted into the school mathematics curriculum. It is thus demonstrated how a particular existing research approach can be adopted to consider the introduction of new content.

A current concern in mathematics education as a research domain is that not much attention is being accorded to mathematics. Julie and Torkildsen's chapter proposes and exhibits a method to analyse students' work in order to identify the mathematics involved in such work. Different from the other two chapters in this section, they demonstrate how a method of analysis can be constructed if one is not readily available.



# *1. Developing a Research Instrument for Learner-Centred Classroom Observations: A Namibian Experience*

Hileni M. Kapenda, Ole E. Torkildsen, David Mtetwa and Cyril Julie

## **Abstract**

Although most researchers prefer to adapt or modify existing instruments that relate to their field of interest, the exercise still remains overwhelming and cumbersome. But, occasionally, a need arises for creating a new instrument for a specific purpose. This chapter shows that the process of designing and constructing a research instrument can be challenging and frustrating. The chapter also focuses on some of the significant personal experiences of the lead author's struggle and long journey in the construction of a research instrument for her thesis on learner-centred education in Namibian schools. The main objective for the chapter is to provide some advice to the reader, and especially to an emerging researcher, about the challenges of designing a new research instrument. Considerations about how and why certain decisions have to be made at certain stages become important matters for discussion.

## **Introduction**

In general, the term learner-centred education (LCE) embraces terms such as active learning, exploration, self-responsibility, consideration of learners' prior knowledge and skills, and construction of knowledge rather than passive participation of students (APA, 1997; MEC, 1993; Walczyk

and Ramsey, 2003). Most notably, McCombs and Whisler (1997: 9) defined the concept 'learner-centred' as:

A perspective that couples a focus on individual learners (their heredity, experiences, perspectives, backgrounds, talents, interests, capacities, and needs) with a focus on learning (the best available knowledge about learning and how it occurs and about teaching practices that are most effective in promoting the highest levels of motivation, learning, and achievement for all learners).

According to various studies and reports on the education system in Namibia (specifically after independence in 1990), most teachers in Namibia are experiencing problems with the implementation of learner-centred approaches (Chaka, 1997; Shaalukeni, 2002; Shinyemba, 1999; Sibuku, 1997). Kamupingene (1998: 124) confirms this statement by reporting that, 'there is a lack of common understanding of learner-centered education in Namibia'. The MBEC (1999:15) acknowledges this by stating that, 'even though learner-centered education is a good idea, many teachers have difficulties using it'.

Now, imagine yourself as a novice researcher interested in understanding the implementation of learner-centred (LC) approaches. How would you best assess the application of LC approaches in the classroom? This chapter will endeavour to introduce the reader to some of the phases and challenges the primary author experienced in designing a research instrument for measuring the extent to which LC practices are present in Namibian mathematics classrooms.

### **Phases and challenges of designing an instrument**

Most researchers use research instruments that they have either modified and/or adapted from other sources. One of the reasons for searching for existing sources is the fact that one does not necessarily want to re-invent the wheel. However, it is a truism that even if cognate instruments exist, they normally need tuning to fit the issue that is being addressed. As alluded to above, the study related to the instrument design discussed in this chapter necessitated the exploration of various research instruments that were used for studies that investigated issues on LCE, specifically in Namibian classrooms. Initially, instruments from Sibuku (1997), Shinyemba (1999) and Van Graan (1999) were revised and adapted. Some of the main

## *Research Instrument for Learner-Centred Classroom Observations*

reasons for adapting the instruments are: (1) the three authors carried out their studies at primary and junior secondary schools whilst the interest was on senior secondary schools; and (2) the focus of the studies was on (a) first graduates of Basic Education Teacher Diploma (BETD) perceptions of learner-centred approach to teaching, (b) provision of effective learning environment by BETD Inset teachers, and (c) teachers' understanding of concept LCE equal to group work, respectively.

During the initial stage, the primary author tried to focus on the main objectives as a guide for the design of an instrument. These objectives were: (1) to determine the extent to which secondary school mathematics teachers implement LC approaches in their classrooms; and (2) to determine the nature of classroom challenges and problems experienced by mathematics teachers in their teaching when applying the LC approach.

Many doubts arose as to how to best design a research instrument that would ensure that appropriate and relevant data were collected. After searching and reading related literature, the lead author came across some instruments that were more or less in line with her area of interest. Figure 1 presents an extract from the first attempt at a research instrument.

Most of the questions in section B of Figure 1 were adapted by putting the focus on mathematics and mathematics teaching. The questions in section C (from Shinyemba, 1999) were initially given as statements rather than questions as shown above. For example, number 2 initially appeared as 'In learner-centred education the teacher provides regular feedback to learners'. This statement was also given as a first choice. However, in the revised (adapted) version it was changed into a question. We thought that questions were more clear and straightforward than statements, from the respondents' point of view. The primary author also added her own starting question (number 1) in section C because it addresses the lesson introduction. The aim of the questionnaire in Figure 1 was to give an overview of mathematics teachers' perceptions about LCE in terms of definitions, problems and challenges experienced during teaching, as well as to indicate the extent to which they claim they are practising LCE.

**Figure 1: Teachers' views on LCE\***

In this section, please express your own personal views on Learner-Centred Education/Approaches.

**SECTION B:**

1. What do you understand by the term 'Learner-Centred Education'?  
\_\_\_\_\_  
\_\_\_\_\_
2. Describe the role of a mathematics teacher in 'Learner-Centred Education'.  
\_\_\_\_\_  
\_\_\_\_\_
3. Describe the role of a learner in 'Learner-Centred Education'.  
\_\_\_\_\_  
\_\_\_\_\_
4. How often do you use 'Learner-Centred Approaches' in your mathematics classrooms?  
 1. Never  2. Sometimes  3. Very Often  
Elaborate on your choice: \_\_\_\_\_  
\_\_\_\_\_
5. What problems do you encounter in using 'Learner-Centred Approaches' during your teaching mathematics classes? (list the problems)  
\_\_\_\_\_  
\_\_\_\_\_
6. What other factors are affecting the implementation of Learner-Centred Education in your mathematics teaching?  
\_\_\_\_\_  
\_\_\_\_\_
7. Have your views about 'Learner-Centred Education' changed since you heard about it?  
 1. Yes  2. No  
If yes, explain how your views have changed: \_\_\_\_\_  
\_\_\_\_\_

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**SECTION C:** Please answer all the questions by putting a cross [X] in the appropriate box.

### HOW OFTEN DO YOU:

1. Start your lesson introduction by using learners' experiences and background and then later build your lesson on the information provided?  
 1. Always  2. Sometimes  3. Not at all
2. Provide feedback to your learners?  
 1. Always  2. Sometimes  3. Not at all
3. Give learners individual assistance?  
 1. Always  2. Sometimes  3. Not at all
4. Expect the whole class to complete or finish the tasks given at the same time?  
 1. Always  2. Sometimes  3. Not at all
5. Encourage your learners to participate in class discussions?  
 1. Always  2. Sometimes  3. Not at all

\* Adapted from: Sibuku (1997) and Shinyemba (1999)

Before piloting the questionnaire, the instrument was given to a group of colleagues (including the co-authors of this chapter) who provided useful comments and amendments to the questionnaire. The feedback given had certain impact on the questionnaire as the primary author corrected grammar and rephrased or rearranged most of the questions. Figure 2 presents the amendments.

The amended instrument was then piloted using a group of 30 mathematics teachers from different educational regions in Namibia as a convenient group at that particular point in time. These teachers had gone through a two-year in-service training course called the Mathematics and Science and Extension Programme (MASTEP) at the University of Namibia in 2003. The pilot study yielded the following outcomes:

First, mathematics teachers in the MASTEP course held different views and perceptions about LCE. Most of them described LCE as a paradigm shift in educational setting that involved active participation of learners in classroom activities. Second, these mathematics teachers also mentioned several problems that they encountered in using LC approaches in their teaching. These included, among others, factors such as classroom

management, not enough time for planning, shortage of teaching resources, noise, chaos and large classes (overcrowding), to mention just a few. Third, the majority of the MASTEP teachers taking mathematics also indicated a fair degree of using LC approaches in their teaching.

**Figure 2: Adaptations of some initial questions on LCE questionnaire**

<p><b>SECTION B:</b></p> <p><b>Before adaptation</b></p> <ol style="list-style-type: none"><li>1. Explain in your own words what you understand by the term 'Learner-Centred Education'.</li><li>2. Describe how you perceive the role of a teacher in a 'Learner-Centred Approach'.</li><li>5. Do you encounter problems in using 'Learner-Centred Approach' during your teaching?</li></ol> <p><b>After adaptation</b></p> <ol style="list-style-type: none"><li>1. What do you understand by the term 'Learner-Centred Education'?</li><li>2. Describe the role of a mathematics teacher in 'Learner-Centred Education'.</li><li>5. What problems do you encounter in using 'Learner-Centred Approaches' during your teaching mathematics classes? (List the problems.)</li></ol>
--

Blaikie (2004: 15) suggests that a research design, including the research instruments, should be subjected to scrutiny by an audience wider than those closely involved with the research study. In order to open the instrument for scrutiny by such a wider audience, a short paper entitled 'Mathematics Teachers' Perceptions of Learner-Centred Education: A Case of the MASTEP Teachers in Namibia' (Kapenda, 2004) was read at an international conference on science and mathematics education.

After some considerations and reflections on the feedback received after presentation of the short paper, the following shortcomings surfaced: (1) Section B of the questionnaire would provide opinions and views about teachers' implementation of learner-centred approaches rather than giving the exact details of their daily activities in the classrooms – the kind of details that Merriam (1998: 21) refers to as the 'reality' of the findings. (2) Because of the qualitative nature of the study and in order to cater for the second objective of this study, it was clear that this instrument was inadequate. Therefore, it was imperative to revise the instrument in order to cater for this aspect. Based upon this, the decision was made to do

## *Research Instrument for Learner-Centred Classroom Observations*

classroom observations as well as to hold interviews with the respondents while ensuring at the same time that the method chosen suited its purpose (Wragg, 1994: 2). Figure 3 is an extract from what is named 'Classroom Observation Schedules' (COS) on LCE.

**Figure 3: COS for LCE activities\***

<p><b>A. LCE/non-LCE Strategies Used (check all that apply)</b></p> <ul style="list-style-type: none"><li><input type="checkbox"/> 1. Group work</li><li><input type="checkbox"/> 2. Pair work</li><li><input type="checkbox"/> 3. Individual work (assignments)</li><li><input type="checkbox"/> 4. Open-ended questioning (e.g. why, explain, clarify, etc.)</li><li><input type="checkbox"/> 5. Relate lesson to learners' experience and knowledge ('action knowledge')</li><li><input type="checkbox"/> 6. Teacher uses real-world examples to explain some mathematical concepts</li><li><input type="checkbox"/> 7. Teacher uses some manipulatives (hands-on) during teaching</li><li><input type="checkbox"/> 8. Teacher uses a variety of classroom activities that involve learners in hands-on activities</li><li><input type="checkbox"/> 9. Teacher gives frequent and appropriate feedback</li><li><input type="checkbox"/> 10. Teacher is not concerned too much about time management</li><li><input type="checkbox"/> 11. Teacher uses whole group call responses most of the time</li><li><input type="checkbox"/> 12. Teacher varies his/her teaching approaches (combines lecture, activities, demo, etc.)</li><li><input type="checkbox"/> 13. Teacher lectures most of the time</li></ul> <p><b>B. Indications that Learners are Actively Engaged (check all that apply)</b></p> <ul style="list-style-type: none"><li><input type="checkbox"/> 1. Learners 'talk and act' more than 'sit and listen' in calls</li><li><input type="checkbox"/> 2. Learners initiate questions and comments often</li><li><input type="checkbox"/> 3. Learners are able to use their 'action knowledge versus school knowledge' to explain mathematical concepts</li><li><input type="checkbox"/> 4. Learners are presenting information to others<ul style="list-style-type: none"><li><input type="checkbox"/> (i) On the chalkboard</li><li><input type="checkbox"/> (ii) Talking to the whole class</li><li><input type="checkbox"/> (iii) During group (or pair) discussions</li></ul></li><li><input type="checkbox"/> 5. Learners are using the following materials:<ul style="list-style-type: none"><li><input type="checkbox"/> (iv) Mathematical sets (tools)</li><li><input type="checkbox"/> (v) Manipulatives</li><li><input type="checkbox"/> (vi) Others (specify) _____</li></ul></li><li><input type="checkbox"/> 6. Learners appear to be animated and interested</li></ul>
---

**C. Overall, what is your estimate of how often the teacher uses LCE strategies effectively?** (Note: indicators for effective use: achievable lesson objectives, related to meaningful class activities, more points from A and B indicators above)

- 1. All the time
- 2. Most of the time (more than half of the class period)
- 3. Some of the time (less than half of the class period)
- 4. Seldom or never

*\* Adapted from: Van Graan (1999) Classroom Observation*

The outline of this instrument had not changed much from the original source. Here the lead author tried to restructure the different sections of the questionnaire and added a few items here and there. The aim of this instrument was to rate the extent to which teachers practise LCE in the classroom. The instrument was not tested in the classroom, but it was discussed with supervisors. At the end of the discussion it was agreed that the instrument needed modification because it was prone to subjectivity. The first author immediately realised that it was very difficult to get consistent (and therefore reliable) results using this instrument – the COS instrument, for example, does not have a rating scale that provides clear demarcations of events happening in the classroom. It also fails to give a clear indication on how to measure the nature of LC activities. Using relevant literature, the lead author therefore designed another instrument, as shown in Figure 4.

**Figure 4: LCE monitoring scale**

Name of School: _____	
Name of teacher: _____	
Topic: _____	Date: _____
<b>Learner-centred</b>	<b>Teacher-centred</b>
1. T relates lessons to	Not related to L experience
2. Use group work/pair	Whole class call response
3. T gives appropriate feedback	No feedback/inappropriate
4. T responds to both correct	T ignores L questions
5. Use of teaching aids	No teaching aids available
6. L use manipulatives	No manipulatives available

## Research Instrument for Learner-Centred Classroom Observations

7. L are engaged investigative	No meaningful tasks for L
8. Pupil-pupil interactions	No interaction
9. Teacher-pupil interaction	T controlled interaction
10. T asks more 'why, explain'	More recall questions
11. Gender balance	Gender bias

At this juncture, the primary author realised that she was not paying enough attention to all the objectives of the study; which meant that there were mistakes in the construction of the instrument. She carried out a pilot study at one of the local schools for a period of approximately three weeks using the LCE monitoring scale above. The discussion with the co-authors revealed two main problems: (1) The reliability of the instrument (due to subjectivity). That is, when and how does one decide the extent of rating whether the teacher is balancing learner-centred and teacher-centred approaches, or s/he is at the extreme? (2) The instrument is comparing learner-centredness with teacher-centredness rather than measuring the extent to which mathematics teachers practise LCE in the classroom. Therefore, using this instrument would change the focus of the study. Advice was given to design another instrument. Portions of this instrument are given in Figure 5.

**Figure 5: Classroom observation checklist\***

In the checklist below, mark the box which best reflects your observation of the teacher's practice. Where necessary make additional comments on your observation.

**A. INTRODUCTION**

Lesson Introduction

1. No introduction, i.e. no connection is made with previous lesson.  
No direction for new lesson. No greetings.

2. Links with past lesson but no real focus for present lesson.

3. Links with past lesson and clear focus for present lesson.

4. Lesson is clearly contextualised and learners' interest is aroused.  
Attention is focused.

COMMENT (Was the lesson appropriately introduced?)

---

---

**B. PRESENTATION and RESOURCES**

**B1. EXPLICIT ORGANISATION OF GROUP WORK**

- 1. No group work.
  - 2. Only two or three learners interact. Others just listen.
  - 3. Group of learners with limited interaction/interact when teacher motivates.
  - 4. Groups of pupils discuss problems, questions and activities by themselves.
- COMMENT (Does the organisation relate to the type of lesson?)

---

---

**B2. PUPIL-PUPIL INTERACTION WITHOUT TEACHER**

- 1. Pupils don't question each other or probe for details.
- 1. Pupils question each other in secret because this is not allowed/ encouraged by the teacher.
- 3. Pupils only question or help other pupils when prompted to do so by teacher.
- 4. Pupils freely enter into discussions with each other.

COMMENT (How is the frequency of interactions between pupils?):

---

---

**B3. WHOLE CLASS TEACHER-PUPIL INTERACTION**

- 1. Totally controlled by the teacher.
- 2. Mainly controlled by the teacher.
- 3. Teacher creates opportunity for pupil-pupil interaction.
- 4. Control of interaction shifts between pupils and teacher.

COMMENT (If no group work, what kind of pupil-pupil interaction is taking place, if any?) (Frequency):

---

---

**B4. USE OF RESOURCES/MATERIALS/AIDS e.g. texts, chalkboard and notebooks**

- 1. No materials available for pupils or teacher to use.
- 2. Only the teacher uses the materials in front while the learners are observing.
- 3. Some learners use materials.
- 4. Learners share and use materials.

COMMENT (Name materials used and frequency; if no materials used):

---

---

\* Adapted from: Adler, Lelliot and Slonimsky (1997)

## *Research Instrument for Learner-Centred Classroom Observations*

With the help of one of the co-authors, we decided to test the instrument above using the recorded video lessons from the pilot study. At this stage the primary author was excited about the instrument because she thought it was the best. Wrong! The instrument looked great on paper, but the minute we took our pencils and got ready for recording the data we got stuck like a big lorry in the mud. The primary author did not know where to start and how to proceed with the different sections provided in the research instrument. She therefore noted several weaknesses in the instrument that were worth taking into consideration: (1) The instrument did not have a consistent rating scale. (2) The sections that represent different classroom activities were categorised to the extent that it was difficult for the researcher to do the rating consistently. (3) The instrument was too long (it covered ten pages). This made the recording procedure very difficult because one had to page through several items before locating the required item. (4) This meant that one would expect different results using the same instrument – the issue of consistency was therefore minimal, if not absent. (5) She also started doubting the internal validity of the instrument. She questioned how congruent the findings would be with ‘real issues’ and the issue of whether she was measuring what she wanted to measure (Merriam, 1998: 201) became crucial at this stage. Specifically, she realised that this was the fourth instrument in a row, and yet she had still not succeeded in addressing the issue of measuring the extent to which teachers practice LC activities.

At this juncture, the primary author was advised to give a brief presentation about her pilot study at a seminar to PhD students. She presented a ten-minute video segment and asked her colleagues to write short vignettes. The discussion session highlighted the following issues: (1) The research instrument should have at least three LC dimensions derived from literature (excluding teacher-centredness). (2) She should come up with indicators for each LC dimension in order to guide her decisions during data collection periods. (3) She should tally the occurrences of the events she would be observing. Below is an example of what she called the ‘Lesson Observation Schedule’ (LOS).

Figure 6: Example of a Lesson Observation Schedule

LCE Dimensions (derived from literature)	Indicators	Occurrence (use tally)	Comments (on what is going on)
<b>A: Learners' active involvement in lesson</b>	1. Student-student interaction		
	2. Teacher-student interaction		
	3. Learner-initiated questions		
<b>B: Learners' experiences are used</b>	1. Daily living references		
	2. Connections to other subject areas		
	3. Connections to prior math knowledge		
	4. References to indigenous situations		
<b>B: Higher-order learning tasks are present</b>	1. Problem solving (tasks)		
	2. Problem posing		
	3. Explanation by students (why?)		
	4. Investigations		
	5. Extensions of the lesson		
	6. Projects (small)		

Figure 7: Indicators and descriptors\*

Indicators	Descriptions and examples of indicators
A: (1) Student-student interaction	Interactions about math ideas or topic(s) [not matters unrelated to math lesson. E.g. 'let's meet in the hall']. Examples: (a) Asking for clarification ['what does the teacher mean by....?'] (b) 'Do you know how to solve this problem?' (c) Giving an explanation about math topic(s). (d) Any other relevant interesting things (including non-verbal communications).
(2) Teacher-student interaction	Interaction about mathematical ideas. Examples: (a) Giving or asking for an explanation/clarification. (b) Content dialogue between teacher and students. (c) Any relevant discussion around mathematics topics.
(3) Learner-initiated dialogue	Examples: (a) 'What do you mean by...?' (b) 'Can you please explain...?' (c) Content of the dialogue.
B: (1) Daily living references	E.g. 'How do you balance your current account at the end of the month?'
(2) Connections to other subject areas	E.g. 'In Physical Science, you learned how to calculate the distance travelled using velocity equation.' Note: These references could come from anybody in class (teacher or learners).
(3) Connections to prior math knowledge	E.g. 'Using algebraic equations (expressions), calculate the mean for the following...' Note: Include things covered before or presumed already familiar to learners.
(4) Reference to indigenous situations	E.g. 'A woman in the village weaves beautiful baskets. What types of symmetries are portrayed by her designs?'
C: (1) Problem-solving tasks (Polya)	No routine tasks, not just 'solve for x' problems. E.g. 'Given a right-angled triangle with sides labelled a, b, and c. How do you prove that $a^2 + b^2 = c^2$ ? Use diagrams or cardboards or any relevant materials to solve the problem.
(2) Problem posing (T and L)	Generation of problems by teacher or learner or both.
(3) Explanation by learners (Why?)	E.g. Learners give their own explanations.

(4) Investigations (through making hypotheses, enquiry, experimental)	E.g. 'Given circular objects of different sizes, strings, and rulers investigate why pie (22/7) is a constant.'
(5) Extensions	Teacher or learners ask questions or elaborate on the work under discussion. Instances that are going on beyond the already established facts.
(6) Small projects	Learners are given small projects to do or they report back on the project they did earlier on.

\* Compiled by Kapenda

The lead author tested the LOS instrument using video lessons from the pilot study. She also tried to verify the consistency of the instrument by coding at least two lessons more than once (i.e. by watching the lesson more than once) in order to determine the instrument's consistency. Through repetitions of watching recorded video lessons, the variations were found to be minimal. However, she kept in mind the fact that the reliability of qualitative data can be improved through triangulation of methodologies (Merriam, 1998; Cohen *et al.*, 2000). Moreover, Cohen *et al.* (2000: 129) highlight several threats to validity and reliability in observations that include, among others: (1) the researcher's unawareness of important antecedent events; as well as (2) the reactivity effect due to the presence of the observer (just to mention a few). The primary author was therefore satisfied to use the instrument in the main study, providing that the necessary adjustments were made as the need arose.

## Conclusion

Designing and constructing research instruments is not an easy process. It is worth mentioning that the phases (or stages) of constructing a research instrument are non-linear. This means that one has to move back and forth in terms of critical thinking and reflections at each stage. The process is an interactive one because it is subjected to public scrutiny. Specifically, in this case colleagues as well as co-authors were involved in providing constructive feedback. As can be realised by now, apart from reading and consulting various resources and literature, the process also requires good organisation of thoughts and ideas, fine reflection on certain issues (why one way and not another way), as well as consistency in one's work. Each stage or phase requires critical thinking and evaluation of certain issues; namely, usability, reliability and validity. Although these constructions are not measured in qualitative studies in the same way as in quantitative

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ones, their consideration remains important. Specifically, the consultation of peers and supervisors provided critical thoughts of enquiry in the design of this research instrument.

We argue that irrespective of whether cognate instruments exist, studies differ in terms of their contexts and sites of implementation and thus require adaptation to be effective in a particular setting – not only as a goodness-of-fit issue. Adaptation is also crucial with respect to ownership. Ultimately, the researcher must own the instrument and one of the most effective mechanisms to ensure personal ownership is through redesign and adaptation.

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## 2. *Introducing New Content into a School Mathematics Curriculum: The Case of Cryptology*

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*Few false ideas have more firmly gripped the minds of so many intelligent men than the one that, if they just tried, they could invent a cipher that no one could break.* (Kahn, 1996: 763)

*Concealment, codes, and other types of ingenious communication.*  
(Butler and Keeney, 2001)

### **Abstract**

Developing learning resources forms an important part of a school mathematics curriculum implementation. This chapter argues for a change in the way we do analysis for developing learning resources. An argument is forwarded for an understanding of the main concepts within the topic as well as a historical and didactical analysis thereof in order to make statements with respect to the teaching and learning of the topic. For this analysis, the topic of cryptology is used as an example. The chapter concludes with recommendations to curriculum designers to revisit the accepted practice to adapt already historically and didactically analysed materials, and warns on the consequences of the currently used methods.

## **Introduction**

The development of instructional materials is an important aspect of curriculum development. It becomes even more important when new content is introduced into a school mathematics curriculum. The current practice in South Africa is to have workshops where the curriculum advisers for school mathematics give in-service training on the content of the new curriculum to teachers of school mathematics. No training with respect to material development is given and an example is usually given as an activity to explore a section of the topic under discussion.

This chapter argues for a historical and didactical analysis of the topic under discussion, as well as a conceptualisation thereof. The topic chosen for this purpose is cryptology. Cryptology refers to 'cryptography, cryptanalysis, and the interaction between them' (Barr, 2002: 2).

The first part of the chapter scrutinises the topic of cryptology. This section aims to explain cryptology as a cryptosystem. In order to understand this cryptosystem, it is important to have a sense of where the overall concepts, discussed in the cryptosystem, fit in. This is followed by an elaboration of the different concepts important to cryptology and their relationship with a cryptosystem. The highlighting of the important concepts within cryptology is done so as to inform the discussion on the historical and didactical phenomenology later on. The section concludes with a figure to outline the cryptosystem and to position the important concepts in the cryptosystem.

The second part of the chapter presents a historical and didactical phenomenological analysis of cryptology. An important aspect neglected when developing new curricula is the link between the historical developments of the knowledge constructs embedded in the subject matter. The consideration of the historical development of knowledge constructs might (or might not) point towards different learning possibilities for the topic under scrutiny.

## **Cryptology**

The word 'cryptology' has its origins in ancient Greek. Cryptology is derived from *kryptos*, meaning hidden, and *logos*, meaning word. The field of cryptology has two divisions, namely cryptography and cryptanalysis. So whenever the word cryptology is used in the text, it refers to cryptography, cryptanalysis and the interaction between them (Barr, 2002: 2). Cryptology is also known as the study of codes.

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Over the years, people have used secret messages. The need for secret communication has occurred especially in diplomatic, military and financial affairs. With the increase in electronic communication, it has become essential to safeguard such communication by introducing secrecy measures. There is thus a great deal of interest in the ways of making the transmission of messages of a sensitive nature to a next person or institution more secure.

### **Cryptography**

The aim of cryptography is to allow two parties A and B to communicate in such a way that C – a listener, intruder or opponent – is not able to understand what is being said. Cryptography is also seen as a discipline to keep communications private (Barr, 2002; Stinson, 1995; Beutelspacher, 1994). In order to keep the communication private, it is obvious that it cannot be conveyed in the same or understandable text that is commonly used. Nor should these private communicative texts be such that they are easily analysable by a third party. In cryptography the easily understood and commonly used text is referred to as the 'plaintext'. The secret text is known as the ciphertext. The word 'cipher' comes from the Hebrew word 'sapher', which means number. The objective of cryptography is the conversion of plaintext to ciphertext, and vice-versa. Ciphers can be seen as mere substitutions in that a letter of the alphabet is substituted by another letter – it could be by one letter, two, or more. A code, on the other hand, is an algorithm, key or a rule for changing a legible message into an intelligible form. In order to change an intelligible message into readable form, one has to use some sort of codebook for these changes.

The process of changing the legible text, also called the plaintext, into an intelligible form is called enciphering or encoding. The reverse process – that is, changing the intelligible text (also called the ciphertext) into plaintext – is called deciphering or decoding.

Menezes, Van Oorchot and Vanstone (1997) go a step further and define cryptography as: 'the study of mathematical techniques related to aspects of information security such as confidentiality, data integrity, entity authentication, and data origin authentication.' For a message to be hidden from prying eyes, a key or algorithm is used to make it secure. This key or algorithm takes on different forms. Historical examples of keys used in sending messages include battens (scytals), linear equations and shifting

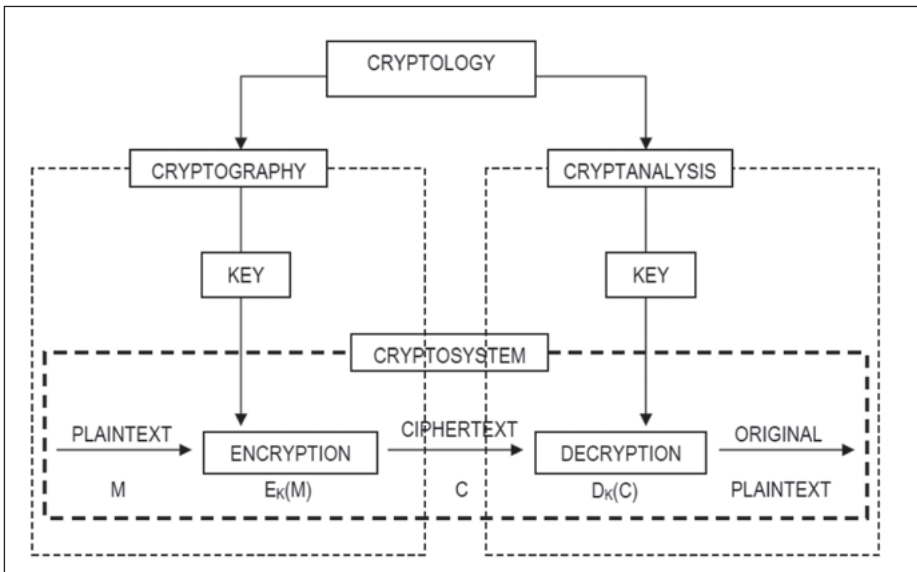
of letters. The importance of keeping the key secret is summarised by the Kerchoffs Principle, paraphrased in Singh (1999: 12) as follows:

Don't underestimate the enemy. The idea is not to keep the encryption and decryption algorithm secret. The main idea is to keep the key itself secret.

### Cryptanalysis

Cryptanalysis is the process of converting a received message from ciphertext into plaintext. The person involved with breaking the ciphertext (secret message) is called a cryptanalyst. Based on the discussion above, the Figure 1 gives a summary of how cryptology is seen as a cryptosystem.

Figure 1: Diagrammatic representation of cryptology and its components



### Phenomenology

Phenomenology can be described as an objective inquiry into the logic of essences and meanings of trying to make sense of a topic. This objective enquiry can take on different forms. Possible forms are a theory of abstraction, deep psychological description, or an analysis of consciousness (Thévenaz, 1962: 37). Phenomenological analysis means approaching the study object, the phenomenon, as free as possible from

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conceptual presuppositions. The aim of phenomenological research is to obtain insights into the essential structures of these phenomena on the basis of mental examples supplied by experience or imagination and by a systematic variation of these examples in the imagination.

Freudenthal (1983a), however, goes a step further by describing a method for studying relations between mathematics, history and education. He distinguishes between *phenomena* and *concepts*. Phenomena refer to that which we want to understand, make sense of, or structure; while concepts are the thought processes which organise these phenomena. Based on this, Freudenthal (1983a: 28–29) defines phenomenology as follows:

Phenomenology of a mathematical concept, a mathematical structure, or a mathematical idea means, in my terminology, describing this nooumena in its relation to the phainomena of which it is the means of organizing, indicating which phenomena it is created to organize, and to which it can be extended, how it acts upon these phenomena as a means of organizing, and with what power over these phenomena it endows us. If in this relation of nooumenon and phainomenon I stress the didactical element, that is, if I pay attention to how the relation is acquired in a learning-teaching process, I speak of didactical phenomenology of this nooumenon. (...) if 'is ... in a learning-teaching process' is replaced by 'was ... in history', it is historical phenomenology.

Within the context of this chapter, historical phenomenology and didactical phenomenology have to be clarified. Historical phenomenology is the study or probing of historical contexts wherein certain mathematical concepts are present in order to make sense of why and how they came up in these contexts. Didactical phenomenology, on the other hand, is the study of relationships 'between the mathematical concepts and the phenomena in which they arise with respect to the process of teaching and learning these concepts and their applications' (Bakker, 2003).

This brings us to one of the aims of this chapter: to make a study of cryptology from two stances, i.e. from a historical and didactical stance. What now follows is a historical phenomenology of cryptology. The chosen examples are organised chronologically and are by no means exhaustive.

## **Historical and didactical phenomenology of cryptology**

According to Freudenthal (1973; 1991) learners should be given the opportunity to re-invent, in a guided way, the concepts and ideas in a particular mathematical domain. He states:

The young learner recapitulates the learning process of mankind, though in a modified way. He repeats history not as it actually happened but as it would have happened if people in the past would have known something like what we do know now. It is revised and improved version of the historical learning process that young learners recapitulate. 'Ought to recapitulate' – we should say. In fact we have not understood the past well enough to give them this chance to recapitulate it. (Freudenthal, 1983b: 1696)

From this it is clear that Freudenthal, and by implication the Realistic Mathematics Education movement, views it as important that development work in the domain of mathematics for school teaching and learning should take into account the historical development of the domain. The purpose of this consideration is to ascertain whether learning trajectories which emulate the historical unfolding of the domain can be determined. A consideration of this nature is called a historical phenomenology, and Bakker (2000) describes it as follows:

Exploring the literature on cryptology gave some insights into the links between history and education and opens up avenues for different learning trajectories for cryptology. On developing these learning trajectories, the aim is that learners somehow reinvent, in a guided way, the mathematical concepts ...

In order to make sense of or understand concepts within a mathematical topic, it is useful to look at its history. Freudenthal (1983b) and Stanton (2001) support the notion that studying the history of a topic is good for teaching that topic. Such examination is aimed at determining what motivated its emergence and shaped its development. Dijksterhuis (1990) is of the opinion that the historical analysis of a topic allows learners to have a better understanding of the topic under discussion. Problems that current learners of school mathematics encounter resemble problems that generations before them experienced. With this in mind, I will look for

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historical contexts that open up avenues for cryptological notions and conceptual obstacles that mathematicians and users of mathematics encounter.

A historical study of secret messages is not an easy process. When people write about history, it is usually with respect to people or events, and rarely with respect to concepts. A second problem could be that the topic of secret messages is not an established one that stands on its own in mathematics. The historical phenomenology of secret messages will therefore look at examples within the different contexts in which it was used. Therefore, what follows is instead an exposition of how secret messages were used in war, communication and other contexts. There are also senses of enciphering and deciphering, so it is not strictly 'use' only but also the processes of 'making secret on the one hand and unmaking the secret on the other hand' – this is the crux of the matter in the historical phenomenology.

### **Bald messages**

Herodotus (Singh, 1999) in 'The Histories' chronicled one of the earliest conveyances of a secret message. It is related how Histiaieus, governor of Miletus, and an enemy of the Persian ruler, Darius, secretly communicated with Aristagoras. Histiaieus shaved off the hair on his messenger's head and tattooed a message on his scalp. After a few weeks, the hair on the messenger's head grew back on, covering the message. The messenger was sent to Aristagoras to deliver the message. He had no problems in crossing Persian enemy lines. On arrival before Aristagoras he said: 'Master, shave my head.' This was done and the secret message revealed. Covering of the message was ensured by the hair that grew back on the head.

For the bald message approach, both the enciphering and deciphering keys are shaving of the hair. As the original message remained the same (as inscribed on the head), there were no changes in the plaintext message. The bald message is an example of a plain cipher, as the message did not undergo any changes. The person carrying the message serves as the code as well.

### **A belt**

Another instance in antiquity of relaying a message secretly is provided by Lysander (Laffin, 1964). He relates how a Spartan general and his troops were away from home, Greece, for quite a while. Their allies in the

war, Persia, remained behind to safeguard Greece against their common enemies. One day a messenger arrived at the war front and was brought before Lysander. On asking the messenger what his business was, he could not say. Lysander then saw the broad leather belt around the messenger's waist. Under scrutiny, Lysander found different letters branded into the belt. He took the belt and wrapped it around the long wooden baton he carried with him. In so doing, the scrambled letters aligned into legible words and sentences. The message thus uncovered informed him of a possible uprising in Greece by Pharnabazus from Persia. Wrapping the belt around the baton uncovered the message. Covering the message was ensured by wrapping it around something thicker – the waist of the messenger.

The wooden baton in this method of constructing and deconstructing a secret message acts both as enciphering as well as deciphering key. Turning the belt around the wooden baton also extended the keys to include a certain number of turns for both instances. An outcome of the turns was that the original message was scrambled on the belt after it was unwound from the baton. This is an example of a transposition cipher, meaning the ciphertext contained the same letters as in the plaintext, but in different positions.

### **Fire signals**

Aeschylus, a dramatist, related the story that the fall of Troy (Butler and Keeney, 2001) in 1084BC was news so important that it had to be relayed to Queen Clytemnestra in Argos. The problem was that she was about 805 kilometres away.

Before the Queen left for Argos, it was agreed upon that a visible fire would indicate a good outcome. The Greeks arranged for fires to be lit on nine hills each about 72 kilometres apart. Different fire teams gathered on the respective hills, and on noticing the fire 72 kilometres back, lit their own to notify the next fire team. This, being the first recorded use of long-range communication, took about 11 minutes to travel the length of Greece.

### **Flag signals**

During the 1800s, fleets of ships communicated with each other by way of flags. This innovative way of communication was used by the British by hoisting flags whose designs, lines, shapes and colours each had their own specific meaning.

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In the Battle of Trafalgar (1805) between the British and French forces, use of a new signal system proved decisive in Britain winning the war. After much consultation with his flag lieutenant, the following message was sent by Admiral Horatio Nelson using seven flags: *'England expects that every man will do his duty'* (Butler and Keeney, 2001: 38). The message inspired the British to a victory over the French troops.

### **Quilt code**

The quilt code was developed by slaves in America to indicate escape routes to Canada. According to Tobin and Dobard (1998), the different designs each conveyed a different instruction. Although the slaves could follow the instructions given on these quilts (generally hung on washing lines), outsiders and even slave owners could not make sense of them.

### **Hobo messages**

As the economic depression increased in the 1930s, more and more people lost their jobs and became wanderers. In their wanderings, they often used signs, marks and symbols on sidewalks, houses, towns and cities to communicate different meanings. Only hobos understood this secret language of symbols.

### **Sports codes**

Signs by way of number calls, hands and fingers are a prominent feature of various sorts of games. Any game on a baseball field is rife with hand signals. Rugby players also use numbers to indicate a code for finding a lineout jumper when throwing in a ball at a line-out.

For the fire, flag, quilt, hobo and sport messages substitution ciphers are included. They all have in common the fact that symbols in whatever form have been used to indicate different things. For example, the fire was a symbol of good news, whereas the designs on the flag denoted different words. In the case of the quilts and hobo messages, patterns and markings translated a language only to be understood by the people concerned. Concerning the sports codes, these signs and signals are there to indicate the play that is about to take place, and is aimed at keeping the opposition guessing.

For the examples listed under substitution ciphers, the symbols, patterns, fires, etc. indicate the encryption keys, while the decryption key was the translation of these into a plain message or an action.

## Pig Latin

Pig Latin was developed by children as a way to keep their communication secret or confidential and has been in use since the 15th Century, according to Kahn (1996). If two children communicated, they used Pig Latin to keep their communication secret from a third party. The Pig Latin system works as follows:

- Words that start with a vowel (A, E, I, O, U) have 'way' appended to the end of the word.
- Words that start with a consonant have all consonant letters up to the first vowel moved to the end of the word and 'ay' appended at the end.
- 'Y' is counted as a vowel in this context.

The sentence *'Please pass me the yellow spoon'* changes to *'Easeplay asspay emay ethay elloyay oonspay'* in Pig Latin.

Pig Latin is a simple form of a transposition cipher where letters in a word change positions. The adding of the 'ay' or 'way' at the end are examples of a null cipher. A null cipher is an example of a cipher that does not change a word or its form. This is one of first examples in history where two ciphers were used.

The above examples can be viewed as 'proto-cryptography', since, in Freudenthal's terms, they are yet not 'organised', but from a phenomenological perspective they provide possible entry points for the topic.

## Conclusion

The examples listed above show how difficult it is to make implicit aspects of cryptology explicit. Although Lysander thought of the shaving of hair to inscribe a message on the head and later allowing the hair to grow back to cover the same message as a way of keeping it secret, this will not be a good example to use for teaching. Both the encoding and decoding keys are the same and the message itself did not undergo any changes.

The observation that the oldest historical examples had to do with secrecy, gives rise to the question: *'Is secrecy a good starting point for the teaching and learning of cryptology?'* The answer is yes. Cryptology has secrecy or confidentiality as its aim. The historical examples show the messages had elements important to cryptology. Some of these elements are the encoding key, decoding key and the different types of ciphers.

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Another observation from history is that the idea was to keep messages/communication secret. This alludes to the importance of the key/rule in encoding messages. The more difficult the key/rule, the more difficult it will be to decode the message.

For the teaching and learning of cryptology, the historical examples need changes or revision. Firstly, most learners have their own understanding of what secrecy is and use it, unwittingly, in different situations; for example, in communication when using Pig Latin in situations of play. Secondly, not all the historical contexts are suitable for instruction. How many learners would be interested in deciphering flag signals or hobo messages? The example of the belt, however, is an appealing context to start the teaching of cryptology. It has elements of a practical activity as well as introducing a transposition cipher.

The examples of history serve to introduce different ways of communication to keep messages secret. In all these messages the way of hiding the message – namely, the key – was a central concept. For the teaching and learning of cryptology it seems it would be best to introduce the topic of cryptology by way of secrecy, and furthermore to introduce learners to the different ciphers in order to render messages intelligible.

This chapter set out to show how the concepts important to cryptology started back in history. Although only a few of these concepts were discussed, it shows the importance of the conducting of historical phenomenology for the designing of instruction material. This opens up ways for designers of curricula to explore the links between history and education. This could lead to a better understanding of the topic under discussion and give a bigger picture of the topic to be covered.

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# 3. *Analysing Learners' Written Work for Open Mathematical Tasks*

Cyril Julie and Ole-Einar Torkildsen

## **Abstract**

Current reforms in school mathematics require that learners engage in open-ended mathematical tasks. The solution procedures for such tasks are not always immediately identifiable and learners invent their own solution methods. These solution procedures might appear as idiosyncratic and display features that are deemed as non-mathematical. In this chapter it is contended that a more thorough look from a mathematical vantage must be given to this seeming idiosyncratic way of working. The chapter thus presents and demonstrates a method of analysing learners' written work from a mathematical point of view.

## **Introduction**

In qualitative research, data primarily appear in the form of actions (performances and gesticulations of participants), utterings (words and other sound expressions) and scribblings (written words, diagrams, doodlings, symbols, etc.). This variety of data pieces must in one way or another be ordered, selected and presented for analysis and interpretation. In recent years a variety of methods have emerged to both analyse and present data obtained via actions, utterings and scribblings.

Gerdes (1994) in his ethnomathematical project has concentrated actions such as basket weaving executed during the construction of artefacts by Mozambican peasants. He then reproduces these actions himself and describes them in terms of mathematical themes. This can be viewed as *static decoding of actions in mathematical terms*.

Rather than resorting and in some way forcing analysis to fit the canonical prescriptions of research, we would argue that analytic tools are dependent upon the issue the researcher wants to illuminate. As scientists construct and use machines for analysis to conduct their scientific analyses (Pickering, 1995), so social science researchers construct their machinery for analysis. The machinery they construct is highly context-specific and normally constructed in real-time during analysis. This chapter deals with the analysis of scribbles. We describe, exemplify and discuss a method for analysing the written work of open problems of learners with minimal input of teachers during the learners' engagement with the situation for which they seek some mathematical solution.

### **Naturalistic inquiry**

Because the naturally produced artefacts of learners are analysed, we view the method of analysis falling within the naturalistic inquiry paradigm. Lester (1985) draws attention to four trends of special interest in the research on problem-solving. The first one of these trends is to 'shift away from experimental and toward naturalistic methodologies' (p. 52). He defines *naturalistic* inquiry as:

... a research paradigm is more or less naturalistic depending on the extent to which constraints are imposed on independent, mediating, and dependent variables ... An 'ideal' naturalistic study would impose a very low degree of constraints on these conditions and outcomes, whereas an 'ideal' experimental (scientific) study would impose a high degree of constraints on them. (Lester, 1985: 52–53)

He continues:

... the typical educational researcher characterizes naturalistic inquiry as follows:

- It relies on *qualitative* methods.
- It eschews rigor for the sake of *relevance*.
- It relies on *tacit* knowledge in the formulation of theory.
- It adopts an *expansionist* (as contrasted with a reductionist) stance toward research.
- Its purpose is to *discover theory* and ground it in real-world data rather than verify theory. (Lester, 1985: 53)

## Analysing Learners' Written Work for Open Mathematical Tasks

From Lester and Kerr (1979) and the quotation above, it follows that an analysis can be done on artefacts that are produced in a 'more or less' naturalistic way.

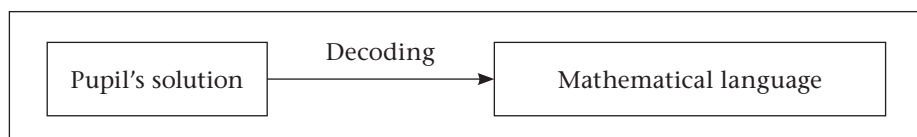
### Analysis method

The purpose of the analysis method to be described is the explicit-making of the mathematical structures inherent in pupils' solutions to some open and investigational tasks. Not only are the tasks open and investigational, but the decision to engage is normally voluntary. This means that the solution-pursuance and the level of engagement are in the hands of the pupils. Mellin-Olsen (1990; 1993) refers to the notion *control of knowledge* and argues that if pupils controlled the *tool level*, the *choice level* and the *goal level*, the level and intensity of their engagement are heightened.

The only concern for the analysis in this research is the uncovering of mathematical structures; and not possible arithmetical errors or inferred cognitive processes. Since the interest is in analysing the produced artefacts of learners in terms of mathematical structures, the process can be viewed as a decoding process. This method could be described as 'analysing the pupils' solutions through the glasses of a mathematician'. The method is thus one of decoding the artefacts which are manifested in the learners' language to the formal mathematical language.

A first level of this analysis procedure is illustrated in Figure 1.

**Figure 1: Direct decoding process**

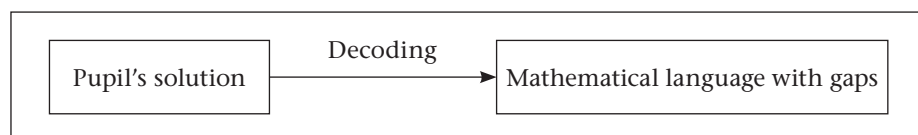


The term 'mathematical language' in this context means a formal mathematical language; a language that uses mathematical symbols/notations. For some of the solutions, or parts of a solution, this decoding process was relatively simple; i.e. the mathematical meaning of the text is clear, and a *direct* decoding is possible. This could be the case if the pupils have already used mathematical symbols in their solution – they use what Pimm (1987) calls a *symbolic* style of recording. It could also be the case if the pupils used a *mixed* style of recording in their solutions (Pimm, 1987), where few mathematical symbols were used in their solution. A

direct decoding could in this case be possible and could also be utilised if the pupils use a *verbal* style of recording (Pimm, 1987), i.e. very few or no mathematical symbols were used by the pupils in their solutions, but the natural language is such that the 'mathematical language' can be easily inferred.

In some cases a direct decoding is not straightforward and the decoding process gives a product with gaps. This situation is illustrated in Figure 2, in which the decoding process leads to an incomplete mathematical description.

**Figure 2: Incomplete decoding process**

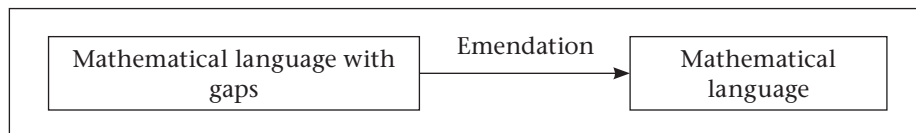


This will usually be the situation if a solution is ambiguous, i.e. for the whole solution or parts of the solution there are several decoding possibilities. Missing or inaccurate use of words and symbols and/or unexpected use of, or combinations of, words could cause this ambiguity.

When a group of people is working on a particular problem or task for a period of time, the members of the group obtain specific knowledge about the problem, the results, the solution procedure and the solution. For the members of the group, some of this knowledge may be tacitly understood. A consequence of that could be that the written solution is comprehensible to the members of the group, but is hard or even incomprehensible for a person outside the group to comprehend.

The goal for a decoding process is presenting a solution in a mathematical language without gaps, as illustrated in Figure 1. When the decoding process ends with a product dressed up in a mathematical language with gaps, it is both necessary and required to 'fill the gaps' in order to get a solution written in a mathematical language. In doing so, an *emendation* process is entered. This process is illustrated in Figure 3.

**Figure 3: Emendation process**



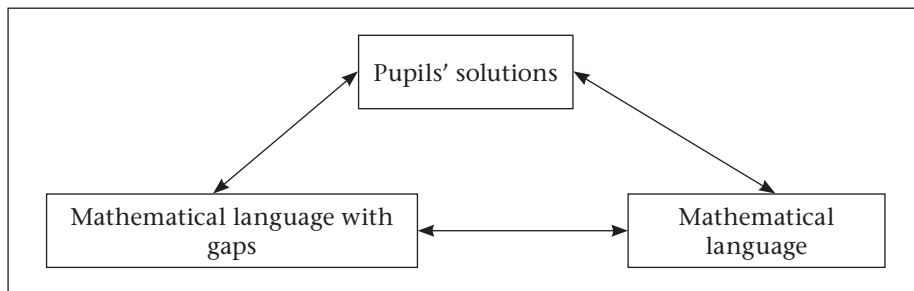
It is not possible, in advance, to describe the time used and the outcome of the emendation process. This process is dependent on several factors. The main factor is the text under consideration and another factor is the nature of the gaps. There is certainly coherence between the text and the gaps, but it is by no means certain that a decoding process is unambiguous with respect to different persons.

During the emendation process it is important that the focus on the text is not too narrow. It is necessary to focus on that particular gap and the corresponding part of the text; but at the same time a holistic view of the text could be of great importance. Text written elsewhere in the work could be the key to a successful emendation process. There is also the possibility that the outcome of the emendation process is 'empty'; i.e. that it is found to be very difficult or impossible to fill the gaps.

During the decoding or/and the emendation processes there is a risk of practising wishful thinking to over-interpret the pupils' solutions, i.e. to 'discover or expose' more mathematics than is actually embodied in the solutions. In order to eliminate or reduce the eventual over-interpretation, it is necessary 'to look back'. This means that after finishing the decoding process and the possible emendation process it is necessary to control the results against the original text. If the outcome of this control is unsatisfactory, the processes, decoding and emendation must continue.

All of the preceding figures have a linear form, but that does not imply that the analysing process is linear. A triangular illustration of the complete analysing process (see Figure 4) seems to be more adequate. Compared with the previous figures, Figure 4 has double arrows, indicating that a 'looking back' process, a control, does not only take place at the end of the decoding or the emendation process. The looking back processes are intertwined with both the decoding process and the emendation process; it is continuous.

**Figure 4: Complete decoding process**



To summarise the analysis process is one in which a knowledgeable person analyses the learner self-generated mathematical artefacts in terms of mathematics. The process is similar to that used in cryptography and comprises the following:

**Transcription:** Learner's writing (text) is rewritten into a more 'formal' mathematical form.

(Cryptography: Coded text is written in the language of origin of the coded message.)

**Translation:** The transcribed text is rewritten in a known (identified) mathematical form.

(Cryptography: The foreign language transcribed text is translated into the language of interest text.)

**Emendation:** 'Missing' mathematical parts are added and the correspondence between this reproduced form and formal mathematics checked.

(Cryptography: An authenticity test.)

If this process leads with some certainty to a known formal mathematical product, then this product is declared the most probable one which conforms to the learner-generated product.

Regarding the methodological demands of research, the trustworthiness of the analysis lies in descriptions which are so truthful and convincing that others can in some way re-walk the analysis journey. Both the activity and the decoding process should therefore be open to scrutiny by others.

**Examples**

**Example 1**

The example below (Whittles, 1997) deals with an activity where Grade 8 learners had to decode MYDLAV with coding rules given as:

*The letters operate in pairs.*

*First code letter of pair = Three times the first letter of the decoded pair + twice the second letter of the decoded pair*

*Second code letter of pair = The first letter of the decoded pair + twice the second letter of the decoded pair*

The result and the way learners went about obtaining it is shown in Figure 5.

**Figure 5: Learners' produced work for a decoding activity**

M	Y	D	L	A	V
20	8	14	6	7	5
20	8	14	6	7	5
$\frac{20}{8}$	$\frac{-6}{2}$	$\frac{-6}{-8}$	$\frac{-4}{-2}$	$\frac{-5}{2}$	$\frac{-1}{4}$
$\frac{12}{6}$	$\frac{1}{2}$	$\frac{4}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{2}{4}$
$2\sqrt{12}$	$2\sqrt{2}$	$2\sqrt{8}$	$2\sqrt{2}$	$2\sqrt{2}$	$2\sqrt{4}$
6	1	4	1	1	2
L	E	N	E	E	T

From this produced work, the Gaussian elimination strategy can be developed as follows:

$$\begin{array}{l} R1 \\ R2 \end{array} \left| \begin{array}{cc} 3 & 2 \\ 1 & 2 \end{array} \right| \begin{array}{l} 20 \\ 8 \end{array}$$

$$\begin{array}{l} R1' = R1 - R2 \\ R2 \end{array} \left| \begin{array}{cc} 2 & 0 \\ 1 & 2 \end{array} \right| \begin{array}{l} 12 \\ 8 \end{array}$$

$$\begin{array}{l} R1' = \frac{R1'}{2} \\ R2 \end{array} \left| \begin{array}{cc} 1 & 0 \\ 1 & 2 \end{array} \right| \begin{array}{l} 6 \\ 8 \end{array}$$

$$\begin{array}{l} R1' \\ R2' = R2 - R1' \end{array} \left| \begin{array}{cc} 1 & 0 \\ 0 & 2 \end{array} \right| \begin{array}{l} 6 \\ 2 \end{array}$$

$$\begin{array}{l} R' \\ R2' = \frac{R2'}{2} \end{array} \left| \begin{array}{cc} 1 & 0 \\ 0 & 1 \end{array} \right| \begin{array}{l} 6 \\ 1 \end{array}$$

It is not claimed that the learners did perform the Gaussian elimination procedure. Rather the identification of this strategy in the learners' work is the result of analysis done by someone more knowledgeable and having an array of higher level mathematical procedures at her/his command.

### Example 2

The Hundred Square

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	15	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

## Analysing Learners' Written Work for Open Mathematical Tasks

This table contains the first hundred natural numbers.

If we pick out a  $3 \times 2$ -rectangle from the table, for example:

72	73	74
82	83	84

and multiply the numbers in opposite (diagonally) corners,  $72 \times 84 = 6048$  and  $74 \times 82 = 6068$ , we find that the difference of their products is 20.

- Pick out other  $3 \times 2$  rectangles and carry through the same procedure. What are your findings?
- Explore this procedure for different type of rectangles, e.g.:
  - $4 \times 2$
  - $5 \times 2$
  - $4 \times 3$What are your findings in each of the cases?
- Try to formulate a rule or a pattern (relation)!
- Can you explain (prove) why your rule for the  $3 \times 2$  rectangle is true?

It should be noticed that the symbol  $\times$  does not mean or indicate multiplication. In Norway, the symbol for the multiplication operator is a dot (cdot),  $\cdot$ . The symbol,  $\times$ , is frequently, or usually, used to indicate the size or the dimension of a rectangle, *length* $\times$ *height*. In the original Norwegian text the symbol  $x$  was used instead of the symbol  $\times$ , which is preferred in this text.

The text of the task was organised in such a way that it guided the pupils to carry through systematic investigations. These investigations had to be carried out in several directions, which meant that several independent variable quantities became an integral part of the task. For example, such variable quantities can be:

- The position of the figures*, i.e. where in the table (hundred-square) the rectangles have been located.
- The size (dimension) of the rectangles*.

The sizes of the rectangles depend on two independent variables; one variable if the rectangle is a square. It is convenient to introduce some symbols and terms. The complete process, picking a rectangle from the

given table, and calculated according to the given algorithm, is called the *rectangle-algorithm*, or simply the *algorithm*. For this algorithm is used the symbol  $R_{m \times n}(x)$ , where  $m$  and  $n$  respectively means length and height of the rectangle, and  $x$  is the number which is located in the upper left corner of the rectangle. The variable  $x$  is then a variable for the position to the rectangle, and  $m$  and  $n$  for the size.

This answer was given by a Grade 3 class with nine- to ten-year-old pupils. The outcome of their investigation of the rectangles can be summarised in the statements:

$$R_{3 \times 2}(x) = 20, R_{4 \times 2}(x) = 30, R_{5 \times 2}(x) = 40, \text{ and } R_{4 \times 3}(x) = 60$$

On the basis of their findings, the class formulated this relationship:

When the rectangle increases by one (e.g. from  $3 \times 2$  to  $4 \times 2$ ), the difference increases by 10.

The stated relationship is not unambiguous or unique. It opens up for different interpretations, and a direct decoding process is not possible.

There are two terms in the relationship that have to be discussed or interpreted. These terms are 'the rectangle increases by one', and 'difference'. According to the degree of stress that is put on the number-example included in the statement, the interpretation leads to statements that can be classified as more or less general.

The interpretation of the word 'difference' will be addressed first. It will be argued that the term is used as a name for  $R_{m \times n}(x)$ . There are at least two arguments that support this interpretation. Firstly, the last operation that is carried out in the algorithm is subtraction, which implies that the answer of the algorithm  $R_{m \times n}(x)$  is expressed as a difference, and hence it is practical to call the answer a difference. Secondly, this interpretation is confirmed by what the class has written elsewhere: 'All differences within the same type of rectangle are identical.'

What, then, about the term 'the rectangle increases by one'? Isolated from this context, the term 'the rectangle increases by one' is without any meaning or sense, but in this context it has several possible interpretations.

What shall be *increased by one*? The *length*, the *height* or *both*?

The *both* alternative, that both the length and height in the rectangle

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increases by one at the same time, is found to be very unlikely. The reason for this conclusion is mainly based on the method used when the class wrote the results concerning the rectangles; when going from one rectangle to the next only one of these two variables was increased.

If no attention is attached to the given number-example it means that the statement is valid for all types of rectangles when either length or height is increased by one. If so, the class has formulated a general statement for all the rectangles. Using the earlier introduced symbols, this interpretation implies that the relationship can be decoded:

If the length of the rectangle is increased by one then:

$$R_{(m+1) \times n}(x) = R_{m \times n}(x) + 10 \quad (1)$$

Or, if the height of the rectangle is increased by one then:

$$R_{m \times (n+1)}(x) = R_{m \times n}(x) + 10 \quad (2)$$

If the number-example is stressed to a higher degree – i.e. the statement is only valid for rectangles with length 2 – the interpretation of the statement is less general. In this case the relationship can be symbolised as:

$$R_{(m+1) \times 2}(x) = R_{m \times 2}(x) + 10 \quad (3)$$

Considering equations (1), (2) and (3), the interpretation (3) is the most likely. The interpretation (1) is very unlikely since the class has observed that  $R_{4 \times 2}(x) = 30$  and  $R_{4 \times 3}(x) = 60$ . The increase in the differences in this case is 30.

The interpretation (2) is possible. From the class's answer it is not clear whether they have explored any rectangular types other than the four mentioned earlier. If they, for example, had also investigated  $R_{3 \times 3}(x)$  or  $R_{3 \times 5}(x)$ , they would most likely have observed or discovered that this interpretation was incorrect. However, on the basis of the presented number-examples, the interpretation (2) cannot be rejected, but it is held as less likely than the interpretation (3).

The reason for this is that in three out of four presented number-examples the rectangles were of the type  $m \times 2$ , the same types as exemplified in their relationship.

## **Conclusion**

In current school mathematics much emphasis is placed on learners tackling open and non-routine problems. Invariably, this will lead to records of pupils' work that might be at variance with the known algorithmic and neat presentation of solutions. In fact, in order to assess learner competences from the perspective of what learners can do rather than what they cannot do, will require teacher competence to identify forms of learner mathematical reporting beyond the surface. We argue that the kinds of decoding of learners' scribbles described above will put additional demands on mathematics teacher work and resources available for schooling in mathematics. These additional demands call first for more resources. In a climate of managerial education it is highly unlikely that resources will be available for the materialisation of in-depth analysis of learner mathematical production in real classrooms. This will also more likely be the case for schools in Late-Developing Countries than for schools in developed countries. A consequence of this is that, in participating in international comparative assessments which aim at assessing student performance on open and non-routine problems such as the Programme for International Student Assessment (PISA) test for Mathematical Literacy (OECD, 2000), Late Developing Countries will always end up on the lower rungs of the comparative ladder. However, this does not mean that learners in Late Developing Countries should not have experiences with open and non-routine problems. Rather, a balance between experiences with routine and non-routine problems, which seriously takes constraints into account, should be found.

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# Theme: Access

Difficulties experienced in coming to grips with mathematical and scientific knowledge, especially by entry-level tertiary students, are well recorded. This section focuses on the efforts embarked upon in some sub-Saharan countries to develop an understanding of this phenomenon and to reflect upon possible pathways for dealing with the underlying issues.

Moru *et al.* consider the obstacles students encounter in their grappling with understanding as the limit of a sequence. Using existing theoretical perspectives such as epistemological obstacles and APOS theory, they argue that obstacles are not only made evident by errors in the answers that students give to tasks; they may also exist in correct responses that students give to tasks. They suggest that students' understanding can be enhanced if they are exposed to different kinds of representation of the limit of a sequence and if simple functions are used at the beginning of a course. Furthermore, it is recommended that the idea of limit should be dealt with as a coordinated pair of processes; that students be exposed to a variety of examples of sequences and that explicit strategies should be embarked upon to develop students' awareness of the difference between everyday notions and the strict mathematical one of the limit concept.

The chapter by Holtman and Marshall focuses on the ways in which the University of the Western Cape (UWC) historically has attempted to improve the access and retention of underprepared students in undergraduate science programmes. Interventions to address issues of access and student retention and success have taken on various forms, beginning with the 'infusion' model of academic development adopted in the 1990s, then shifting towards a Science Foundations Programme (SFP) from early 2000s, and then to the reconfiguration of the latter into the present extended curriculum programme (ECP). The authors describe the structure and philosophy of the SFP and explore the lessons learned from the SFP. They examine the integration of the key SFP educational philosophy and practices into the new extended curriculum programme and some of the challenges that remain in mainstreaming academic development initiatives at UWC.

The concept of a function plays a pivotal role in mathematics. It is encountered by students in schooling and students carry the understanding they developed during this phase of their education into studies in higher education institutions. This understanding is highly influenced by the way the construct is presented in school textbooks. The chapter by Nyikahadzoyi *et al.* explores the conception pre-service teachers hold of this important mathematical construct. The analysis weaves the historical and psychological perspectives of the development of the concept of function in ways that led the researchers to draw conclusions which have important implications for instructional practices in the wider mathematics curriculum at both secondary school and tertiary level in Zimbabwe and beyond. It was found that the prospective teachers had different versions of the definition of a function. This led to the conclusion that students should be given an opportunity to acquire certain flexibility in using these modes of expression and representations.

Access to tertiary education in many Late-Developing Countries can only be realised through distance education. Tsvigu *et al.* present an argument for the importance of considering different learning styles when designing learning resources for students utilising distance education to acquire a tertiary education. Various ways of profiling students' learning styles are assessed and, using constructs from calculus as background, it is demonstrated how a particular mechanism for ascertaining the learning styles can be applied to both to students' produced work and to texts used in distance education. They recommend, based on the results of their analysis, that one way to promote epistemological access could be through the incorporation of learning styles in learning materials.

# *4. Epistemological Obstacles in Understanding the Limit of a Sequence: A Case of Undergraduate Students at the National University of Lesotho*

Eunice K. Moru, Jan Persens, Trygve Breiteig and Joyce Ndalichako

## **Abstract**

This chapter reports on a case study in which epistemological obstacles in understanding the limit of a sequence by mathematics students at undergraduate level were investigated. The study was conducted at the National University of Lesotho (NUL). A group of 56 mathematics students at undergraduate level was used as the sample of the study. Data was collected via interviews and questionnaires. The data were analysed using the APOS framework. Obstacles in understanding the limit concept have been identified, classified and discussed. It is shown that such obstacles are not only made evident by errors in the answers that students give to tasks, but they may also exist in students' correct answers. Implications for classroom practice of the findings as well as indications for further research are made.

## **Introduction**

Serious problems of understanding of fundamental calculus concepts by students in tertiary education, colleges and universities are evidenced by a body of research studies conducted in different parts of the world – for instance, the UK (Tall and Schwarzenberger, 1978), the USA (Davis

and Vinner, 1986; Aspinwall and Miller, 2001), Poland (Sierpinska, 1987), Sweden (Juter, 2003), and South Africa (Bezuidenhout, 2001). Lesotho seems to be no exception to this problem. Regardless of the country's intention to produce more qualified science, mathematics and technology personnel; mathematics, and in particular calculus, continues to be a problem for mathematics students. Many university undergraduate science students are failing calculus and are ending their education in mathematics. The problems are especially visible in the first and second years of their studies. On average, only 23% of the initial intake to the science faculty at NUL qualify to pursue mathematics in their second year of study. This prevents students from majoring in science subjects such as physics, which requires a pass in calculus. NUL is the only university in Lesotho, and the success or failure of its students has a large impact on the socio-economic development of the country.

The situation is quite disturbing for Lesotho and the authorities acknowledge that: 'The supply and availability of Science and Technology have been inadequate over the years, in both number and disciplines, to meet the country's growth needs.' (Government of Lesotho, 2002: 21).

## **Research question**

The major purpose of the study was to investigate the epistemological obstacles that second-year mathematics students encounter in understanding the limit of a sequence. The choice of the limit concept is based on the central position that it occupies in the learning of calculus, as well as the epistemological difficulties research has identified in connection to this. The research question addressed by the study was therefore:

What epistemological obstacles do undergraduate mathematics students encounter in understanding the limit of a sequence?

Questions of this nature have been investigated by mathematicians and mathematics educators elsewhere, especially in case studies, using different methods and analytic perspectives in interpreting the data collected. Some theoretical perspectives that were used include theories of understanding (Sierpinska, 1990), relation between concept image and concept definition (Tall and Vinner, 1981; Aspinwall and Miller, 2001), process-object (Dubinsky, 1991; Tall, 1991), and actions-process-object-schema (Cotrill *et al.*, 1996, Juter, 2003).

While this study has similarities with some of the afore-mentioned studies, it also has some differences. The context is Lesotho and the

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National University. A study of this kind has not previously been conducted in Lesotho. At NUL, only scientific calculators are used in teaching the limit concept in calculus – not computers or graphing calculators. In the context of this study, English was the medium of instruction and was the second language of students in the sample group. Students therefore had to cope with sublime ideas in mathematics while receiving instruction in a second language.

### **Theoretical basis**

This study will build upon research on the development of ideas and on growth of knowledge.

### **Epistemological obstacles**

In this section the construct ‘epistemological obstacles’ is discussed. How are they defined, what are indicators of their existence in history and in education, and how may they be overcome? At the end of the section, an operational definition of ‘epistemological obstacle’ that was used in the study will be stated.

Bachelard (in Cornu (1991)) introduced the notion of obstacle and describes epistemological obstacles as part of the knowledge that was generally satisfactory at one time in solving certain problems. This satisfactory aspect has anchored the concept in the mind and made it an obstacle. Brousseau (1997) defines an epistemological obstacle as a piece of knowledge that was once interesting and successful, but in a different context it is revealed as false or unadapted.

What the two definitions have in common is that epistemological obstacles are pieces of knowledge that retard the speed of learning. This piece of knowledge may be successful in one context, but not another. Tall (1991: 10) explains the existence of these types of obstacles by referring to the *generic extension principle*. It reads:

If an individual works in a restricted context in which all the examples considered have a certain property, then, in the absence of counter-examples, the mind assumes the known properties to be implicit in other contexts.

An example may be the sequence  $\{0.9, 0.99, 0.999, \dots\}$  where, since the sequence is tending to 1, the limit may be seen as tending to 1, as a process.

Brousseau (1997) suggests that in order for an obstacle to be overcome, there must be a sufficient flow of new situations that it cannot assimilate. This will destabilise it, making it ineffective, useless and wrong in the new context, which will necessitate reconsidering it, rejecting it or forgetting it. Sierpiska (1987), on the other hand, hypothesised that in order to overcome these obstacles a mental conflict is bound to occur and, therefore, a didactical situation. However, her findings show that not in every case that a mental conflict is encountered is an epistemological obstacle overcome. This creates many challenges to educators in identifying and diagnosing the sources of such obstacles. This is because in every learning situation old knowledge has to be replaced with the new, and epistemological obstacles play an informative role in the process. It is the objective of didactics, therefore, to understand these obstacles and use them by creating situations that will enable students to meet them, though not necessarily in the same way as they were encountered in the historical development of the concept (Brousseau, 1997).

Both Brousseau (1997) and Cornu (1991) point out that epistemological obstacles are made evident by errors in the answers that students give in responding to selected tasks and questions. But such errors are not due to chance. In fact, they persist and resist being rejected, as they are components of the acquired piece of knowledge. They further show that the problems and difficulties that students experience in learning are also good indicators of the existence of epistemological obstacles because they show periods of slow development of the concept. Therefore, in pursuing research when an error, a difficulty or a problem is identified, it should be reformulated not in terms of lack of knowledge; but of knowledge, false or even incomplete (Brousseau, 1997: 94).

As a result of this discussion, the term 'epistemological obstacle' is defined as a piece of knowledge in this chapter. Sometimes the acquired piece of knowledge may be erroneous in one context, but correct in another. Two types of epistemological obstacles can therefore be distinguished: those that may be correct locally but not generally, and those that may not be correct in any given context. The first type can be explained in terms of the generic extension principle and the latter cannot. The analysis of the data collected in the study and reported in this chapter considered these two types of epistemological obstacles.

In order to understand the type of epistemological obstacles that learners encounter in learning calculus – and with the limit concept, in particular – it is important to look at some of the problems that led to the slow development of this idea.

**Epistemological obstacles in the history of the limit concept**

Infinite series are sequences of a special kind. If  $\{a_i\}$  is a sequence then

$$S = a_1 + a_2 + a_3 + \dots = \sum_{i=1}^{\infty} a_i$$

is an infinite series which could also be represented numerically, geometrically or verbally. A sequence may also be generated from the partial sums of a series, i.e.:

$$S_n = \sum_{i=1}^n a_i .$$

While the notion of infinitely large is related to the number of terms of a sequence or series, the infinitely small quantities are related to the nature of terms.

The historical epistemological obstacles related to limit of a sequence included problems related to the sum and convergence or divergence of an infinite series or sequence, and the concepts of infinitely large and infinitely small (Boyer, 1968; Kline, 1972; Hollingdale, 1989; Cornu, 1991).

Zeno's paradoxes from the 5th Century BC played a role as historical obstacles. They lead to processes that can be explained in terms of a series

$$\frac{1}{2} + \frac{1}{4} + \dots + \frac{1}{2^n} + \dots$$

and to the interpretation: In order to go a finite length, one must cover an infinite number of well-defined points, and so must get to the end of something that has no end (Kline, 1972). Zeno himself could not solve the paradoxes. His work was a forewarning of the deep crisis in the foundation of mathematics following the discovery of the calculus in the late 17th Century. Hazy use of infinitesimals brought up contradictions and paradoxes. An epistemological problem with infinitely small quantities was to know whether they did exist as numerical entities. Were they zero or non-zero? Could they be described as 'ghosts of departed quantities', as Berkely called them, or 'souls of departed quantities', as Newton referred to them? D'Alembert's viewpoint was that a quantity is something or nothing. If it is something, it has not yet vanished; if it is nothing, it has vanished. The supposition that there is an intermediate state between the two is a fantasy. Cauchy took the first step in resolving the crisis and overcoming

the epistemological obstacles by replacing infinitesimals with limits.

It took mathematicians centuries to solve the idea of convergence of an alternating series. A popular example being Grandi's series:  $1-1+1-1+1-1+ \dots$ . One major problem with such series was that when approached from different angles, it gave contradictory answers. For example, when worked out as:  $(1-1) + (1-1) + (1-1) + \dots$  the answer would be 0, and the result of  $1- (1-1)- (1-1)- (1-1)- \dots$  would be 1. Some mathematicians came up with the result

$$\frac{1}{2},$$

which may be consistent with the sum,

$$1 + k + k^2 + \dots = \frac{1}{1-k}$$

by assigning the value  $k = -1$ . Such obstacles were to be overcome through the so-called arithmetisation of analysis by Weierstrass and his followers (Eves and Newsom, 1965).

### **Obstacles in students' understanding**

Monaghan (1991) found that some students' problems related to the understanding of limits stem from the ambiguities inherent in the four phrases *tends to*, *approaches*, *converges*, and *limit*. While, in the mathematical sense, the three action verbs are dynamic, the word *limit* is static. In the mathematical context the stated verbs are associated with the limiting processes. However, in the study by Monaghan some students used the phrase 'approaches' in the static sense. That is, for example, as a way of thinking, and they also talked about 'different *approaches* to mathematics'. In their experience students had also encountered the word '*converge*' as associated with rays of light and now could not see how a sequence of numbers could be said to converge. There are also some inconsistencies in mathematical contexts concerning the use of the word 'approach'. For example, in a case where the limit of say  $a_n = k$  (constant) as  $n$  tends to  $\infty$  has to be obtained, the process of  $a_n$  tending to the limit appears static as the number that is said to be approached is already reached.

Monaghan is not the only researcher who had pointed out the problems of language in learning limits. Other researchers who have associated the problems of limited understanding with language include Taback (1975), Tall and Schwarzenberger (1978), and Davis and Vinner (1986). Taback

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shows that the word 'reach' in limits, as used by the mathematicians, refers to the neighbourhood of a point, but to some pupils it refers to landing on a point. Tall and Schwarzenberger (1978) suggest that the phrase 'as close as we please' lacks precision in that it does not show by how close one can go in quantitative terms. The interpretation of the word 'close' is also problematic in that it suggests being near, but not coincident. If it meant coincident, it might have been stated explicitly, they say. Davis and Vinner (1986) point out that the terms 'limit' and ' $n$  goes to infinity' invariably remind us of ideas that do not constitute part of our mathematical representation of the concept.

Tall and Schwarzenberger (1978) suggest that problems that students have in understanding the limit of a sequence are due to the fact that in the school syllabuses sequences are played down or sometimes even omitted; however, series are covered at a deeper level. Since the series are mostly understood as an infinite sum, the treatment of sequences is fundamental to the understanding of series.

Tall and Vinner (1981) point out that some of the problems that students encounter include the interpretation that sequences such as  $S_n = 0$  for  $n$  odd, and  $\frac{1}{2n}$  for  $n$  even, are not one but two sequences. Hence, such sequences should not have one but two limits. Other misconceptions, revealed in the work of Davis and Vinner (1986), are the influence of specific examples and misinterpreting one's own experience. Cornu (1991) agrees with Davis and Vinner (1986) that school syllabuses are overloaded with monotonic sequences. As a result, when students meet other types of sequences for the first time, they encounter problems. Such obstacles are indicative in the errors that students make when confronted with mathematical problems (Cornu, 1991).

### **The APOS theory**

The limit concept can be described as a coherent collection of *actions*, *processes*, and *objects*, called a *schema* (Cottrill *et al.*, 1996). The theory constructed for this type of understanding is given the acronym APOS. A brief overview of this theory may point to the following.

An *action* is any physical or mental transformation of objects to obtain other objects. It occurs as a reaction to stimuli that the individual perceives as external. It may be a single step response, such as a physical reflex or the act of recalling some fact from memory. It may also be a multi-step

response, but then it has the characteristic that at each step the next step is triggered by what has come before, rather than by the individual's conscious control of the transformation (Cottrill *et al.*, 1996: 171). An action may also be described as a repeatable mental or physical manipulation of objects. Such a conception would involve, for example, the ability to plug numbers into an algebraic expression and calculate. It is a static conception in that the subject will tend to think about it one step at a time. That is, they think about the single evaluation of an expression at a time (Dubinsky and Harel, 1992: 85). In this study, an action has been taken as a situation whereby a finite number of computations have been used to obtain the limit value. It could either be taking one of the computed range values as the limit value, or using the method of approximating to get the limit value – instead of performing the limiting processes indicated by 'tending to' or 'approaching'.

Depending on the situation at hand, the descriptions or processes that have been employed in this study are that a *process* is the transformation of an object (or objects) that has the important characteristic that the individual is in control of the transformation. This means that s/he is able to describe, or reflect upon, all of the steps in the transformation without necessarily performing them (Cottrill *et al.*, 1996: 171). It can also be described as a dynamic transformation of quantities according to some repeatable means that, given the same original quantity, will always produce the same transformed quantity. The subject is able to think about the transformation as a complete activity, beginning with objects of some kind, doing something to these objects, and obtaining new objects as a result of what was done (Dubinsky and Harel, 1992: 85).

Seeing a mathematical entity as an *object* means being capable of referring to it as if it was a real thing. It also means being able to recognise the idea 'at a glance' and to manipulate it as a whole, without going into details (Sfard, 1991: 4). Typically objects are described by their properties, their relationships with other objects, and ways in which they can be used. We might ascertain whether an individual has constructed a mental object in relation to a concept by the way that individual talks about or writes about the concept (Tall *et al.*, 2000: 230).

Three categories of analysis of epistemological obstacles may emerge from this framework. We will look for epistemological obstacles in interiorising actions into processes, in the co-ordination of processes, and in encapsulation of processes into objects.

## **Methodology**

The study followed a case-study design. This choice was guided by the fact that a bounded system (Merriam, 1988), namely a group of mathematics students at NUL, was the focus of investigation. A class of 56 second-year calculus students was used as sample. The concept of the limit of a sequence is covered at this stage. This is also a stage at which a high failure rate in calculus is experienced. The research instruments used in the study were questionnaires and interviews. The questions were formulated in such a way that they should encourage the evocation of the mental constructions proposed by the APOS framework. The themes of the questions were based on historical epistemological obstacles in the development of the limit of a sequence. Since questionnaires have a disadvantage by not probing deeply into respondents' conceptions, interview questions were constructed for this purpose. All interview questions emerged from the questionnaire responses and were used in supporting the existence of a particular kind of knowing that acted as an epistemological obstacle in understanding the limit of a sequence.

To improve the reliability of the research results, low inference descriptors were used (Seale, 1999). This claim had several implications. We used observations in terms that are as concrete as possible, including verbatim accounts of what people said rather than researchers' reconstructions (which might have allowed researchers' personal perspectives to influence the reporting) (Seale, 1999: 148). All face-to-face interviews were recorded, carefully transcribed and presented as extracts of data in reporting the results. The validity of the research results was enhanced by using methodological triangulation. This involves studying the nature of the problem from a variety of viewpoints in order to expand the understanding of the phenomenon under study (Burns and Grove, 1993). If different methods correspond, the researcher becomes confident about the findings (Cohen, Manion and Morrison, 2000). This may also help in comparison of data. A triangulation was achieved by using questionnaires and interviews. Gaps identified in questionnaire data were complemented by data collected using interviews.

The questionnaire was administered to 56 calculus students. Interview data was collected within a period of two weeks after administering the questionnaires. For interviews, 18 students were chosen based on their responses to the questions. In order to qualify for an interview, the subject should have answered nearly all the questions in the questionnaire, with

at least one question answered differently from the majority of the class. Nine subjects were interviewed individually, and the other nine were interviewed in groups of two or three.

In analysing the data, the collected material was read repeatedly to get an overall picture of the type of responses that subjects had given. Students' errors were first identified from the questionnaire data. The answers were provided either through working, their choice of answers from the options provided, or by looking at the incorrect explanations that did not match their choice of answers. Since these errors constitute epistemological obstacles (Brousseau, 1997), conceptions around which they originated were identified. These obstacles were identified from the explanations for the choice of answers given and the interview data. The interviews concentrated on all the answers, both correct and incorrect. Classification of the identified errors was done bearing in mind the three categories developed from the APOS framework.

## **Results and discussion**

We have related epistemological obstacles to student errors, problems or difficulties that they encounter when responding to questions on limit of a sequence. A discussion of the results may now be structured by looking into the three categories from the APOS framework: interiorisation of actions into processes, construction of the coordinated processes, and encapsulation of processes into objects.

### **Epistemological obstacles to interiorising actions into processes**

Within the APOS framework one can arrive at a conclusion about the limit value by a consideration of an infinite number of computations. Some will be performed, and some will not be performed but be contemplated. A subject who considers one or two values, or a finite number of computations, before reaching a conclusion about the limit value, shows an action conception.

A question that revealed a situation where the action conception was made visible is

**Question 1 (b):** Evaluate  $\lim_{n \rightarrow \infty} \frac{(-1)^n}{n}$

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Of the total sample, 45 subjects obtained the correct answer of zero. Since they did not show any intermediate steps, it was not possible to identify the procedures that led to the answer.

Seventeen of the 45 who obtained the correct answer were interviewed. The interviews revealed that none of the 17 subjects obtained the answer by using the limiting process, by either 'tending to' or 'approaching' the limit in the mathematical sense. One subject obtained zero by treating the sequence as a series and using the Ratio Test. The other 16 subjects considered only one number in deciding the limit value; thus revealing an inappropriate application of the action conception. The conception acted as an epistemological obstacle in this context. All 17 subjects obtained the correct answer by implementing inappropriate procedures. One would therefore suspect that there could still be a good number of subjects who obtained their answers by also using inappropriate procedures.

The interviews showed that three sub-conceptions within the action conception mainly led to finding the limit value for the 16 subjects:

- 'Approaches' means 'nearer to'.
- 'Approaches' means 'approximately equal to'.
- Mixed conceptions, action and process, indicating a transition problem.

The results reflecting the three subcategories are presented next.

### **Interpretation of 'approaches' as 'nearer to'**

In this subcategory, four subjects (S1, S17, S19 and S23) reached the conclusion about the limit value by a consideration of only one value, which they considered to be nearer to zero and could therefore be taken to be the same as zero. The following extract reflects this:

R: How did you get zero as the answer?

S1: When I thought of  $n$  as that big number, as the denominator, at the top we will always have 1 or  $-1$ . So, when I divide either  $-1$  or 1 by a very big number we will get a number that approaches zero.

In everyday life, when one approaches a point, the end result would either be finding oneself in the neighbourhood of the point or landing on the point. Thus, 'approaches zero' has been taken as synonymous with 'nearer to' in the case of the subjects. In the mathematical sense 'approaches' is a limiting process and 'nearer to' is not.

### **Interpretation of 'approaches' as 'approximately equal to'**

Five students (S8, S9, S11, S17 and S21) used 'approximately equal to' as a limiting process. The extracts of S8 individually and S11 and S12 in a group interview may show this.

- R: How did you get zero as the answer?  
S8: I look at the  $n$ . If  $n$  gets larger that limit will go to zero.  
R: What do you mean when you say that the limit will go to zero?  
S8: When you take numbers that are large, you divide one negative or positive by a big number, you get approximately zero.  
R: How did you get zero as the answer, S12?  
S12: It is by dividing by a very big number.  
R: How about you, S11?  
S11: I see that when  $n$  is even I will get one and when  $n$  is odd I will get  $-1$  and  $-1/n$  as  $n$  goes to  $\infty$  will be a very big number and when I divide 1 by a very big number it is approximately zero. Because it is 0.0000...  
R: (Intervening) Does it mean that when you divided 1 by a very big number you rounded off?  
S11: Yes I rounded off. I approximated it to zero.

In some mathematical contexts, numbers have a certain degree of inaccuracy. Thus 'approximating' is an appropriate operation in those contexts. In dealing with finding limits, since an infinite number of computations have to be considered, it becomes inappropriate to apply approximation.

### **Having mixed conceptions, action and process – a transition problem**

Five of the 16 subjects (S4, S13, S14, S24 and S 49) had mixed conceptions, the action and the process conceptions, and none of these conceptions was fully developed. Some interview extracts may reflect this:

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R: In 1(b) how did you get zero as the answer?

S24: I know that  $n$  is approaching  $\infty$ . So when you divide by a very big number you get zero.

R: How many big numbers did you consider?

S24: Many numbers.

S49 shows the same transition stage:

R: How did you get zero as the answer?

S49: The numerator is either 1 or  $-1$  and this becomes smaller when we divide by a big number. It gets smaller and smaller.

S24 at first refers to dividing by a big number, an action, and later says 'many numbers', a process. S49 here at first refers to dividing by a big number, an action, and later says 'it gets smaller and smaller', a process.

This section has presented results reflecting how the action conception was considered an epistemological obstacle to the understanding of the limit of a sequence. The next section reports on the results showing the type of conceptions that were used inappropriately in an attempt to form a coordinated pair of processes – a process schema.

### **Epistemological obstacles in constructing a coordinated pair of processes**

The coordinated pair of processes considered in this section refers to  $a_n \rightarrow L$  as  $n \rightarrow \infty$ , via the given formula. Subjects seemed to have problems in constructing the stated mental operation, making errors and encountering difficulty. The errors and difficulties encountered are listed here (these are followed by a discussion showing the conceptions around which the stated errors and problems are centred):

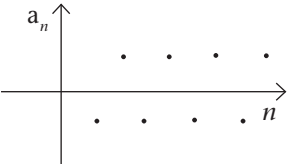
- Perceiving finding the limit of the same sequence in different modes of representation as the same process, but using wrong procedures in implementing the process.
- Inability to generalise a concocted sequence (Tall and Vinner, 1981).
- Having problems in conceptualising the infinite process by 'approaching' or 'tending to' the limit.
- Having problems with finding the limit of a sequence in geometric form.

- Perceiving the limit value as a dynamic object rather than a static one.

### Limit of the same sequence in different modes of representation

The questionnaire was designed in such a way that finding the sequences in some questions like 1(a), 4(b) and 8(b) required the same process. The same sequence was represented in different modes – algebraic, numerical and geometrical. The questions referred to are shown in Figure 1 and an overview of the students’ responses is presented in Table 2.

**Figure 1: Sample questions representing same sequence in different representation modes**

<p><b>Question 1 (a)</b> Find <math>\lim_{n \rightarrow \infty} (-1)^n</math></p>	<p><b>Question 4 (b)</b> Find the limit of the sequence <math>\{-1, 1, -1, 1, -1, \dots\}</math></p>	<p><b>Question 8 (b)</b> Find the limit of <math>a_n</math> when</p> 
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**Table 1: Frequency of students’ responses (%)**

Response	Question 1(a) (Algebraic)	Question 4(b) (Numerical)	Question 8(b) (Geometrical)
1	13	16	11
1 for n even, and -1 for n odd	61	38	41
0	2	0	2
-1	4	5	2
$\infty$	11	9	9
$-\infty$	2	2	2
$\pm\infty$	7	4	5
No limit	2	14	16

Finding the limit of the same sequence as the same process required the ability to start with the same object and end up with the same transformed quantity (Dubinsky and Harel, 1992). Table 1 shows that the

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majority of students get the same limit of the sequence in different modes of representation. The most common answer is that the limit is 1 when  $n$  is even and -1 when  $n$  is odd. The two limits were obtained, while the limit for the given sequence did not exist. This answer was obtained by treating the sequence as two sequences instead of one. The extract from the interview with S49 indicates such a process in finding the limit of a sequence.

R: How did you get 1 and -1 as the limits?

S49: A negative number when squared will give a positive number or to the power even and the odd will give negative.

R: So for odd you will get -1 and for even you will get 1. So, you will get {1, -1, 1, -1, 1, ...}. As you were looking for the limit, what did you think you were looking for?

S49: The number  $a_n$  approaches as  $n$  tends to infinity.

R: So you found two such numbers as your limits?

S49: Yes.

The results fits into the conception that this is not one, but two sequences. Such a response was given by S13 during the interview:

R: Do you take -1, 1, -1, 1, ... to be one sequence or two sequences?

S13: I think these are two sequences.

R: Which are they?

S13: 1, 1, 1, ... and -1, -1, -1, ...

In a study by Tall and Vinner (1981) students regarded the sequence similar to the given one as two sequences. Hence two distinct limits were computed for the sequence. The convergence of the given sequence has been one problem of the past that received great attention because it was a generic example in order to develop calculus, yet the results of working with it were incomprehensible.

### **Generalising an alternating (concocted) defined sequence**

All the subjects (except for two) did not get the limit of given sequence in

**Question 4 (d):** Find the limit of the sequence  $\{\frac{1}{2}, 0, \frac{1}{4}, 0, \frac{1}{6}, 0, \dots\}$

In all cases their responses were that the sequence did not have a formula so they could not work it out. Even in cases where attempts to find the formula were made, they were erased as they did not correspond to the numerical sequence. The subjects were not aware that they had to separate the odd and the even terms

$$a_n = \begin{cases} \frac{1}{n+1} & \text{for } n \text{ odd} \\ 0 & \text{for } n \text{ even} \end{cases}$$

so that any generalisation made should hold for those terms only. But since this is a single sequence the formula should be observed as one:

$$a_n = \left\{ \frac{1}{n+1} \text{ for } n \text{ odd, } 0 \text{ for } n \text{ even} \right\}.$$

Davis and Vinner (1986) suggest that such problems are due to the fact that the syllabuses are overloaded with monotonic sequences, so the shift to the other types of sequences is very difficult. This is confirmed in the interview with S11, who said that he had never seen a sequence like this before:

- R: What does it mean to say that the sequence does not have the  $n^{\text{th}}$  term? Do you mean the formula?
- S19: I tried to find the formula for the  $n^{\text{th}}$  term so I could not get it.
- R: So you were looking for the formula?
- S19: Yes, so I concluded that since I could not find  $a_n$ , I could not get the limit.
- R: Is it possible to find the limit of the sequence only when you know the formula?
- S19: Yes, madam, I think it is because I have been doing it like that.

In all the cases where the sequences were given in a numerical form, the subjects translated these to the algebraic representation and then proceeded with the work to find the answer. S19 does not give a logical explanation for this kind of behaviour. When interviewing S11 and S12, who had not responded to the question, they responded with the following:

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R: Both of you have not responded to this question, why did you have a problem with this sequence?

S11: I have never seen a sequence like this.

R: What did you think you were looking for when looking for convergence of this sequence?

S11: Convergence to some particular value.

R: Ok, what was the problem now about that?

S12: I did not find the function that matches the sequence.

R: Which means that you wanted some general formula that would help you.

S12: Yes.

Unfamiliarity with the sequence was a problem to S11. But, as with the other members of the class, the major problem was that of not being able to translate an alternating sequence from a numerical form to the algebraic.

### **Conceptualising the infinite process of 'approaching' or 'tending to' the limit**

$\Pi$  ( $\pi$ ) is here the object that results from the encapsulation of the process of 'approaching' or 'tending to'. Each number in the sequence is one step in the infinite process of reaching this irrational number. In responding to

**Question 7:** What is the limit of the given sequence:  $a_n = \{3.1, 3.14, 3.141, 3.1415, 3.14159, \dots\}$ ? Why do you think so?

all subjects (except seven) got the correct response. But even though their answers were correct, wrong procedures were used in finding or justifying the answer. When interviewed two of these seven said that they obtained the answer  $\pi$  because all the numbers of the sequence are approximations of  $\pi$ . Hence, finding the limit of this sequence is the same as finding the limit of  $a_n = \{\pi, \pi, \pi, \dots\}$ , which is a constant sequence.

Errors committed by other subjects who obtained incorrect answers, include:

- Convergence is checked by considering the digits that do not change in a number given by extending degree of accuracy (in this case, the numbers chosen were either 3 or 3.1).

- Having problems with the infinite process of approaching.
- That there is no observed pattern.
- The conception that  $\pi$  is not a number.
- The number of decimal places of  $\pi$  is infinite (1, 2, 3, 4, ...).
- The last digits on the right-hand side of the decimal point have to be considered.

Here are some of the questionnaire responses. These are followed by interview discussions confirming the existence of these conceptions:

- S1: 3.1, the decimal number that is constant in all values of the sequence is 0.1 and it shows that it does not increase even when approaching the  $n$ th decimal place.
- S49: This (3.14) is the lowest common limit that is found in almost every case.
- S39: The limit here is 3. Since when we increase the number of decimal places of  $\pi$  the number remains 3 when it is a real number.
- S5: Although the number of decimal places are changing, the limit approaches 3.
- S32: 1, 4, 1, 5, 9. No pattern for this because it is fluctuating. It does not have a pattern.
- S41: The limit is infinity. The numbers keep increasing.
- S44: The limit is infinity.  $\pi$  is an irrational number, which means the number of its decimal places is infinite.

These subjects encounter problems in conceptualising  $\pi$  as a number. Great resistance was also given by S19 due to language and the conception that  $\pi$  is not a number:

- R: You say that the limit of the sequence  $a_n = \{3.1, 3.14, 3.141, 3.1415, 3.14159, \dots\}$  is  $\infty$  as  $n \rightarrow \infty$ . Can you explain how you got this answer?
- S19: How I got this?
- R: Yes. How did you get infinity?
- S19: Madam, this one I cannot explain.

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R: Ok, as we increase the number of decimal places do you think we are increasing the accuracy or we are decreasing the accuracy?

S19: We are increasing the degree of accuracy.

R: Of what?

S19: Of the number  $\pi$ .

R: Of the number  $\pi$ ? So as we go on and on, which number are we getting close to?

S19: To 3.

R: Are we getting close to 3? Here the first decimal place is 3.1 and the second is 3.14, are we getting closer to 3?

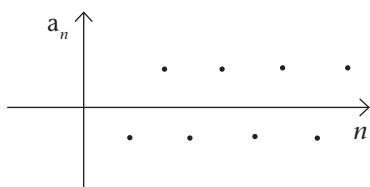
S19: No.

R: To which number are we getting close to?

S19: 3.2.

Increasing the degree of accuracy of the number  $\pi$  should have been taken as the process of tending to  $\pi$ . However, the preceding interview extract shows that the subject at one point moved to the left to get 3.1, and at another he moved to the right to get 3.2. Like other subjects who gave either 3 or 3.1 as the answer, the conception that convergence means meeting at the same point seems to have been a major epistemological obstacle. Converging light rays meet at the same point, so convergence of the terms of a sequence would also be determined by the digits that do not change in the terms of the sequence.

**Question 8(b):** Does this graph of a sequence have a limit? Explain how you obtained your answer.



$$a_n = (-1)^n, n = 1, 2, 3, \dots$$

### **The limit of a sequence in geometrical mode**

In some cases the subjects got wrong answers by using inappropriate methods of finding limits. The most striking was the method used by subjects when finding the limit of the sequence in graphic form:

Here the subjects were to show that the limit does not exist since the odd terms tend to  $-1$ , while even terms tend to  $1$ . Some subjects found the limit to be  $\infty$  or  $\pm\infty$ . These answers were obtained by joining the points of the geometric sequence. Nine subjects employed this method. S11 was among those who joined the points as in Figure 2. In an interview he said that the limit is  $\infty$  because the lines joining the points tend to infinity. S24 and S17, who joined the points as in Figure 3, said that the limit is  $\pm\infty$  because the top line is tending towards  $+\infty$ , whereas the line below is tending towards  $-\infty$ . Alongside the diagram, the algebraic representation of the sequence was given as  $a_n = (-1)^n$ ,  $n = 1, 2, 3, \dots$ , and the same question was asked in both the numerical representation in Question 4(b)  $\{-1, 1, -1, 1, -1, \dots\}$  and the algebraic in Question 1(a). The subjects could not coordinate these modes of representation.

What one sees as the major obstacle here is that subjects were most probably not used to the geometrical representation of sequences, but to the algebraic. They also seem to be so used to joining points of a graph that this was done even in cases where it did not hold. There also seems to be a very serious problem in conceptualising the domain process. The  $n$  values seem not to be considered in order. If they had been, subjects would have realised that the terms of the sequence are alternating. Hence the limit does not exist and cannot be represented by a sequence tending to infinity.

Figure 2: The limit as  $\infty$

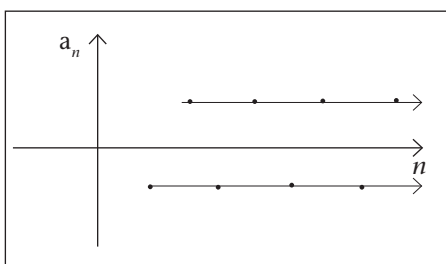
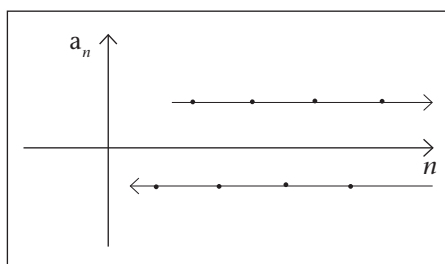


Figure 3: The limit as  $\pm\infty$



### The limit value as an object

In responding to some questions subjects have constructed sentences using the phrase '... the limit approaches' instead of the order '... approaches the limit'. In the mathematical sense, the limit is a static object. So referring to it as if it is something that can be set in motion is a conception that differs from that of the mathematical community. Since the structure of

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the sentence was disturbed, the meaning also changed. Here follow some statements that were constructed by ten out of 18 subjects who displayed this error:

- S5: Although the number of decimal places is changing the limit approaches 3.
- S9: ... the limit will tend to zero.
- S13: Because when the limit of any function approaches a specific number, it is said to be finite.
- S35: ... the limit approaches the fixed number ...
- S37: It is because the sequence converges if its limit approaches a certain number other than infinity.
- S49: The limit is zero when  $n$  is even. The limit approaches zero when  $n$  is odd.
- S53: The limit of  $a_n$  gets closer to 8 as  $n \rightarrow \infty$ .
- S55: The sequence converges whenever the limit approaches a finite number.
- S56: It is because its limit approaches specific and finite value.

In an interview with S49, he was asked what he meant by saying: 'The limit is zero when  $n$  is even. The limit approaches zero when  $n$  is odd.' This was his response to finding the limit of

$$\frac{1}{2}, 0, \frac{1}{4}, 0, \frac{1}{6}, \dots :$$

- S49: Here we see this is a constant function (odd terms 0, 0, 0, 0, ...). So, the limit is zero and here we have  $\frac{1}{2}, \frac{1}{4}, \frac{1}{6}, \dots$  the limit approaches zero.

This was anticipated as a consequence from the argument put forward earlier. In finding the limit of a constant sequence, there seems to be no motion felt in the range, as it feels like one has arrived at the destination as the same number is repeated over and over again as the image. Despite this anticipation, it was still a surprise to find this type of conception in this group. Besides the conception of the limit value as static, interpretations given by some subjects interfered with the mathematical interpretation of the idea of convergence.

### **Epistemological obstacles in encapsulating processes into objects**

A question that was used to check whether or not the interviewees had encapsulated the limiting process into the object was:

**Question 7:** When asked to find ‘the limit of a sequence’, what do you think you are asked to find?

What follows are some of the results from the stated questions. In responding to Question 7, some subjects reflected errors originating from a kind of knowing influenced by everyday meaning of the word ‘limit’ and also by the exposure to examples of monotonic sequences. Three subjects described the limit as the endpoint, one as an interval, one as a boundary and two as to find out if the sequence is increasing or not. The excerpts that follow represent each of the stated categories of responses:

#### *Endpoint*

S9: We are to find the endpoint.

S17: I think by the limit of a sequence we mean where the sequence ends.

S30: We are to find the endpoint of the sequence.

#### *Interval*

S15: I have to find the interval at which the limit exists.

#### *Boundary*

S24: I think I have to find the boundary within which the sequence lies.

#### *Increasing*

S18: I am to find if the sequence is increasing.

S19: As that sequence increases it may approach a certain number.

The *Collins English Thesaurus* (1992: 423) provides a list of synonyms of the word ‘limit’. Among the synonyms the following are mentioned: end, endpoint and boundary. Though these conceptions are appropriate in other contexts, they seem to represent epistemological obstacles to the understanding of the limit concept in the mathematical sense. In saying

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that the limit is the endpoint, one would think that the limit value should be the last term in the sequence. The last term is only identifiable when dealing with finite sequences. The terms 'interval' and 'boundary' carry with them the meaning that the terms of a sequence within a certain boundary or interval can be limit values. But we know that any given sequence can at most have one limit value. These conceptions resonate with other research. Davis and Vinner (1986: 296) describe the limit of a sequence as: 'The number that a sequence of numbers go to' and '... the endpoint for a list of numbers'. Cornu's (1991: 155) list of spontaneous conceptions of limit that students hold, include an interval, the end, and the point (the number), which one approaches and reaches.

Monotonic sequences are sequences that either increase or decrease. Having encountered these types of sequences, subjects seem to assume that all sequences should either increase or decrease. But in the mathematical contexts there are other types of sequences – such as constant sequences or alternating sequences – which neither decrease nor increase. Dealing with a lot of examples of the same kind of sequences will give subjects problems in dealing with a different kind.

The action verbs 'approaches' and 'ends' have been used in the responses given. This shows that full encapsulation of the limit as a static value or as an object had not occurred. Full encapsulation of the process into object would have occurred if the explanations of the limit of a sequence were given without reference made to the processes that gave rise to it (Sfard, 1991).

### **Conclusion**

The results have revealed that errors that students commit; and problems that they encounter in understanding the limit of a sequence are related to conceptions emerging from the dual meaning of terms that mathematics shares with other subjects and also with everyday life. Such terms include 'limit', 'approaches' and 'converge'. Having used these terms in some contexts in which their meanings were applicable, students assume that such meanings are also applicable in the mathematical context. Some of the errors and difficulties were also brought about by the fact that subjects seemed to have been exposed to well-defined monotonic sequences, and when they meet alternating or oscillating sequences they could not coordinate both the domain and the range processes to find the limit values. Subjects also had problems with finding the limit of the same sequence in different modes of representation. The sequence given in the geometrical mode was treated

like a function defined over some interval unaware that the points of the graph of a sequence are discrete. Though some of these obstacles are shared with other undergraduate students elsewhere, there are some differences in the contexts in which the different studies were conducted. A direct comparison could therefore not be made with research results elsewhere. The researchers had prior knowledge that epistemological obstacles are evident in the wrong answers that students give (Cornu, 1991; Brousseau, 1997), but the findings of this study have also revealed and confirmed that not all correct answers are free from epistemological obstacles.

Implications for practice of the findings include exposing students to different kinds of representation of the limit of a sequence, using simple functions at the beginning because of lack of computer technology and graphing calculators. Attention should be paid to looking at the idea of limit as a coordinated pair of processes, so that the domain and the range processes are bound together in finding limits. Students should also be exposed to a variety of examples of sequences, so that they do not encounter problems in dealing with sequences of different kinds. Different meanings of terms with dual meaning should be discussed in mathematics classrooms. Students should be aware that the definitions they bring into the mathematics classroom are not necessarily mathematically correct in every situation. Contexts in which meanings are not applicable should therefore be explicitly discussed with students.

In investigating epistemological obstacles, future research should not only concentrate on wrong answers. The correct answers should also be investigated. Didactical situations that would promote the overcoming of these obstacles should also be investigated. This is because overcoming these obstacles and understanding are complementary processes (Sierpiska, 1990). Since language issues also emerged as crucial, the role of language in understanding the limit concept could also be investigated at an even deeper level.

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# *5. Foundational Provisions in the UWC Science Faculty: Widening Access and Promoting Success*

Lorna Holtman and Delia Marshall

## **Abstract**

In this chapter the authors take the perspective of learning where one views underpreparedness more broadly in terms of ‘epistemological access’ and not merely by focusing on content deficits of entry-level students. The chapter maps out the historical trajectory of academic development initiatives in the UWC Science Faculty, starting with the ‘infusion’ model of the early 1990s, followed by the creation of a separate Science Foundations Programme (2001–2006), which was reconfigured into the present extended curriculum programme (ECP) in 2007.

We outline innovative teaching strategies used in the Science Foundations Programme and look at the infusion of these strategies and academic literacies into the ECP using the introductory physics course as an example. We argue for a careful balance between content and form in order to develop students’ metacognitive awareness.

The chapter concludes with the assertion that if the ECP is to have sustained and significant impact on mainstream teaching practices, it will require institutional commitment and investment to effectively mainstream the lessons learnt from the ECP into all undergraduate science courses in order to improve throughput and success of students in the faculty. We need to do more than propose progressive policy statements on access and retention of students, and put more emphasis on allocation of institutional resource allocation and staffing of the ECP.

## **Introduction**

In South Africa the legacy of the apartheid education system persists, with many learners from disadvantaged school backgrounds being hugely underprepared for science and engineering studies at tertiary level.<sup>1</sup> Since it is unlikely that the quality of secondary education will improve in the short term, it is crucial that tertiary institutions find ways of widening access to students that have the potential to succeed at tertiary level but who enter higher education underprepared for its academic demands.

This chapter focuses on the ways in which the University of the Western Cape (UWC) historically has attempted to improve the access and retention of underprepared students in undergraduate science programmes. Interventions to address issues of access and student retention and success have taken on various forms, beginning with the ‘infusion’ model of academic development (AD) adopted in the 1990s, then shifting towards a Science Foundations Programme (SFP) from 2001–2006, which was reconfigured in 2007 into the present form of an extended curriculum programme (ECP). In this chapter, we will describe the structure and philosophy of this SFP and explore the lessons learnt from the SFP. We will describe the integration of the key SFP educational philosophy and practices into the new ECP and some of the challenges that remain in mainstreaming AD initiatives at UWC.

## **Foundational provision in South Africa: An historical overview**

SFPs in South Africa have a long history, with their inception in the early 1980s.<sup>2</sup> These SFPs were set up at the historically white, English-speaking universities to support the small numbers of black students gaining access to white campuses. Initially, these programmes – termed ‘academic support’ programmes – were small, and aimed to support those black students considered ‘disadvantaged’ or ‘underprepared’ by their inadequate school backgrounds. Since the majority of these students were not first-language English speakers, add-on academic literacy or English courses<sup>3</sup> were introduced into these support programmes, along with generic ‘study skills’ courses and additional tutorials. These programmes were almost entirely separate from the traditional ‘mainstream’ offerings of academic departments.

By the end of the 1990s, there had been a growing shift from an ‘understanding of the construct of “disadvantage” as located in individuals,

to a “historical-structural” understanding locating “disadvantage” in structures that act on individuals’ (Boughey, 2007: 8). There was a shift from a focus on the ‘deficits’ of individual black students towards a focus on the need for institutional change, through curriculum reform and staff development. This was signalled by a gradual shift in nomenclature from ‘academic support’ to ‘academic development’, where the term ‘development’ was intended to indicate the need to develop the capacity of the institution to meet the changed students populations (Volbrecht and Boughey, 2004). AD implied a shift towards integration of foundational provision into the mainstream.

### **The UWC institutional context**

By contrast with the approaches to widening access adopted by the historically white universities, UWC adopted a very different approach to deal with widening access to greater numbers of underprepared students.<sup>4</sup> At that time, there was a recognition that academic ‘underpreparedness’ affected the majority of students at UWC, and so in 1990 an ‘infused academic development’ model was formally adopted by the institution, described as ‘curriculum review and development by lecturers and whole departments, supported by university policies and structures’ (Walker and Badsha, 1993: 6). This infusion of AD initiatives into the mainstream curriculum was coordinated and monitored through an Academic Development Centre (Walker and Badsha, 1993).

Within the UWC Science Faculty, some of these mainstream curriculum innovations were the result of collaboration between AD staff and discipline lecturers (for example, integrating language development into mainstream courses (McKenzie, Keats and Boughey, 1993), and small-group learning in large-classes (Keats and Boughey, 1993)). Other curriculum interventions were spearheaded by mainstream academics with an interest in student learning and curriculum (for example, strategies to foster students’ metacognitive development (Kannemeyer, 1997; Linder and Hillhouse, 1996)).

Despite the formal adoption of the ‘infusion’ AD model in the institution, in practice this was unevenly implemented across the institution and Science Faculty. This was due to a number of reasons, including lack of human resources and inadequate institutional funding for AD. By the mid-1990s, public funding for AD work was waning nationally, and many institutions were not able to continue funding AD posts that had been created on ‘soft’ funding (Boughey, 2007). At UWC, the Academic

Development Centre was disbanded in 1997, with many of the AD experts leaving for other institutions (many of whom now hold key leadership positions at teaching and learning centres nationally).

In 2000, UWC formulated a Teaching and Learning Strategic Plan (UWC, 2000: 1) which set out the university's development as an inclusive and highly flexible 'access institution', with a specific emphasis on access to students 'who have been severely underprepared by the schooling system and who need extensive support'. It was noted that widening access needed to be accompanied by measures to 'develop the academic potential of students and increase the success rate of students who are inadequately prepared for study at tertiary level' (UWC, 2000: 1). There was a recognition that mainstream (i.e. 'infused') curriculum interventions were not sufficient and that foundational courses were also required. In 2001, the SFP in the Science Faculty at UWC was initiated. This programme provided access to students who did not meet normal admission requirements (termed 'Senate Discretionary' students since they had not obtained University Exemption in the Matriculation examinations). While the rationale for these foundation courses was ostensibly to 'widen access', falling enrollment numbers in the Science Faculty at the time point to an additional, more pragmatic goal of meeting enrolment targets (see Osborne, 2003, for similar trends in access programmes in Europe).

### **Recent government policy on foundation programmes**

Since South Africa's democratic transition of 1994, foundation programmes have featured increasingly prominently in government policy as a means to widen access to higher education, as well as to tackle the huge attrition of previously disadvantaged students once they gain access to higher education.<sup>5</sup> According to the Higher Education White Paper (DoE, 1997):<sup>6</sup>

The Ministry will ensure that the new funding formula for higher education responds to such needs for academic development programmes including, where necessary, extended curricula. Such programmes will be given due weight and status as integral elements of a higher education system committed to redress and to improving the quality of learning and teaching.

Since 2000, there have been several cycles of Department of Education (DoE) funding for foundation programmes nationally. This funding has

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recognised that many students who do manage to meet the admission requirements of higher education are nevertheless in need of foundational provision (DoE, 2004: 2):

Very few institutions make provision for students who meet normal admission criteria to pursue extended curricula programmes. The fact that they meet the normal admission criteria does not necessarily imply that they are not at risk, as evident from the high failure and drop-out rates in general.

The most significant foundation funding occurred in 2006, when the DoE earmarked over R100 million for what they termed extended curriculum programmes (ECPs); which are degrees or diplomas that are extended or augmented by certain academic development components, courses or modules (DoE, 2006). In 2007, the UWC Faculty of Science introduced a four-year ECP to replace the pre-existing SFP. This was intended for students who met the normal entry requirements for the Faculty of Natural Sciences, but with low grades. The intention was that the ECP would improve retention and ensure success of these students and in this way also contribute to improved throughput and graduation rates.

Although structurally the ECP was different from the SFP, the educational underpinnings of the SFP and the ECP were very similar. The next section presents the educational framing of these two interventions, and then the following sections describe the structure of the SFP and ECP, discussing challenges and lessons learnt.

### **Conceptualising access and success**

In considering the educational imperative to 'widen access', Morrow (1993) makes the important distinction between formal access and epistemological access. Formal access concerns registration at the institution – relevant issues here are entry qualifications, student fees and access to financial resources, and the physical location of the institution. However, once formal admission into the institution has been secured, there is the further issue of how to engage students with the knowledge of the academic programme for which they have registered. This initiation into the discourses and practices of the discipline is what Morrow terms 'epistemological access'. In the context of the sort of access provided by AD programmes, Moll and Slonimsky (1989) point to the importance of

viewing learning in terms of developing an awareness of the 'ground rules' of a discipline. Here, the ground rules would refer to the values, attitudes and ways of thinking characteristic of a discipline; also to the ways in which new knowledge is produced and what counts as knowledge within a specific discipline (see, for example, Boughey, 1994).

This perspective is echoed in the work of the new literacy studies (NLS) theorists, who see learning as a process of gaining access to the discourse and social practices of a discipline through participation in a discourse community (see, for example, Gee, 1990, 1998; Lea and Street, 1998). The notion of Discourse,<sup>7</sup> as characterised by Gee, is useful in thinking about students' accessing a discipline. For Gee, discourse encompasses the particular ways of 'behaving, interacting, valuing, thinking, believing, speaking, and ... reading and writing' (1990: vii) which characterise a particular community. It is through the use of these characteristics that we can recognise ourselves and others as belonging to the community. From this perspective, successful learning involves entering and then participating in a Discourse community.

This view on learning as successfully accessing a Discourse implies conceptualising learning not merely as a cognitive process of acquiring knowledge and skills, but as a process of accessing a disciplinary discourse through participation in a discourse community, and gradually taking on a particular identity. Sfard's (1998) two metaphors of learning – acquisition vs participation – are useful to highlight this distinction. The *acquisition* metaphor underpins many dominant conceptualisations of learning in undergraduate science education, with descriptions of learning in terms of acquiring concepts, misconceptions, facts, content and material 'covered'. On the other hand, the *participation* metaphor is more closely linked with conceptualisations of learning in terms of identity formation.

In the following section we will describe the SFP as a means of addressing the issues of access and retention of students in undergraduate science studies. In particular, we will focus on the Science Foundations (SF) course, and how it was framed in terms of helping students access the disciplinary Discourse of science and to begin to develop an identity as a scientist.

### **The Science Foundations Programme**

The SFP (which existed from 2001 to 2006) was designed as a foundation programme rather than a remedial (bridging) one. Bridging programmes tend to be backward-looking, focusing on filling 'gaps' in students' school

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science, mathematics and biology knowledge. By contrast, a foundation programme such as the SFP tends to be forward-looking, preparing students for the demands of tertiary education, inducting them into the culture of science and preparing them for life-long learning.<sup>8</sup>

The SFP comprised three year-long courses: the non-credit bearing SF course, the non-credit bearing Mathematics (pre-calculus) course and one of the following credit bearing science mainstream courses: Life Science, Environmental Science, Chemistry and Physical Science.

The other three science courses for the mainstream BSc first year were obtained during year two of the programme. The main vehicle for foundational provision in this SFP was the SF course, and this therefore forms the focus of our discussion here.

### **The Science Foundations course**

The broad aims of the SF course were to foster students' capacity for critical thinking and inquiry, to develop their understanding of the nature of science, and to develop their ability to read science texts and communicate about science. The course encouraged participatory learning and fostered students' exposure to real-life research and scientists. Students also all conducted authentic inquiry-based investigations. The SF course provided foundational provision to students who would go on to a range of undergraduate programmes. It was therefore not rooted in any one particular science discipline, but rather drew on basic overarching principles (the 'big picture' science approach) and concepts from the four science disciplines (physics, chemistry, biology and earth sciences). The intention was to develop students' academic literacy using the science content from these disciplines and to emphasise the nature of the scientific disciplines. In Gee's terms, the SF course aimed to help students access and take on the Discourse of science,<sup>9</sup> where Discourse refers not only to reading and writing science, but also the values, attitudes, beliefs, habits of mind, and ways of thinking and doing that characterise the scientific disciplines.

This explicit focus on helping students access the disciplinary Discourse was especially important for many of the students in this SFP who enter higher education educationally underprepared. Many of these students have views about science that limit their learning; in that they view science as a body of facts to memorise, and their experience of science from high school is largely of science as decontextualised, abstract and alienating

– science as something that happens in a laboratory or in a textbook, but which has little connection to their own lives or their community context. It was important that students’ epistemological conceptions were addressed, through explicit focus on addressing students’ conceptions of learning science and making explicit the nature of science – how scientific knowledge is structured and produced, and what counts as knowledge within scientific disciplines, the social and cultural embeddedness of science, and so on. The focus was on scaffolding their learning by addressing the ‘ground rules’ and exposing them to the ‘inner logic’ of academic practices so that students could overcome the challenges of ‘underpreparedness’ (Steinberg and Slonimsky, 2004). The course also focused on helping to develop students’ identities as scientists through participation in authentic inquiry-based activities.

The structure of the Science Foundation course can be seen in Figure 1 below.

**Figure 1: Outline of Science Foundations course content**

<p><u>Module 1:</u></p> <p><b>The nature of science</b></p> <ul style="list-style-type: none"><li>• The philosophy of science with examples from different disciplines</li><li>• Ways of knowing</li><li>• Contributions of great scientists emphasising African and women scientists</li></ul> <p><b>Accessing science texts</b></p> <ul style="list-style-type: none"><li>• Characteristics of science texts</li><li>• Deconstructing science texts</li><li>• Heuristics for problem-solving and understanding science texts</li></ul> <p><u>Module 2:</u></p> <p><b>Communicating science</b></p> <ul style="list-style-type: none"><li>• Different communication channels for science</li><li>• Representations of science</li><li>• Case studies</li></ul> <p><b>Scientific investigations</b></p> <ul style="list-style-type: none"><li>• The principles of scientific methodology</li><li>• Planning a scientific study</li><li>• Outcomes of scientific studies</li></ul>
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In the section below, we describe aspects of the course design that were oriented towards helping students access the disciplinary discourse of science and begin to develop an identity as a scientist. Extracts from students' interviews are used as illustrations in places.

### ***Making the nature of science explicit***

Traditionally, most undergraduate science classes focus on content; i.e. on the *products* of science (theories, equations, etc.) rather than on the *processes* of science. Discussion around the nature of science (philosophical and historical aspects) continues to be seen as an 'add-on' aspect to traditional courses rather than being infused into the teaching of science itself. Yet research shows that students' views of the nature of science are crucial for determining how students relate to the discipline and how they go about learning (see, for example, Edmundson and Novak, 1993).

An important focus of the SF course was to make the nature of science (NOS) explicit to students, through socialising students into the practices and discourses of science: initiating them into the attitudes, values, habits of mind and ways of thinking characteristic of science, and making explicit the ways in which new knowledge is produced and judged. The approach used to develop students' understanding of NOS is broadly described as an explicit-reflective approach (Khishfe and Abd-El-Khalick, 2002). Historical case studies were included to expand on NOS ideas (Allchin, 2004; Matthews, 1998, 2000). All these are facets of what Gee terms 'Discourse'.

### ***The 'big picture' science approach***

The SF course introduced students to science through a 'big picture' science approach, which emphasises the overarching themes and principles that scientists see as integral and basic to their discipline. For example, evolution is the overarching principle of all biology and, similarly, the foundations of chemistry are reflected in and based on the periodic table. By pointing this out to students, they are encouraged to see the form or structure of a discipline, rather than to see it merely in terms of a set of piecemeal, unrelated facts and concepts. It provides the 'pegs' on which to hang concepts and assists in illustrating the 'big picture' or (conceptual) framework of a discipline.

### ***Science as a human activity***

The SF course presented science as a human activity because we believe students will identify more easily with people and their ideas, as opposed to abstract theories and an ahistorical and asocial representation of science (Holtman, Marshall and Linder, 2004). The latter is usually a result of focusing on content delivery and relying on a traditional mode of delivery; general theories and principles are taught first, followed by the applications of the theory through specific examples.

Throughout the course, students were exposed to real-life scientists and their research projects through the scientific investigations section of the SF course. De Beer (2006) points to the lack of appropriate role models for students from diverse backgrounds; and the SF course focused on the histories of the various science disciplines and the contributions of women and black scientists. Scientists from Africa and their contributions were emphasised.

The strengths of the Science Foundations programme is that it got us to understand science the way it is supposed to be. That is, it gave us a 'behind the scenes' look into how scientists work, generate knowledge, it helped me to see that yes, I could be a scientist despite my background. (De Beer, 2006)

### ***Making the tacit explicit: Reading and writing science texts***

For Gee (1990), reading and writing comprise just one aspect of a Discourse. From an academic literacies perspective, reading and writing are always located in a context, so that generic 'language' or 'skills' courses decontextualised from disciplines are unable to provide students with adequate grounding. Academic literacy needs to be infused into disciplinary teaching (Boughey, 2002; Haggis, 2003). In the SF course, although not a discipline course like physics or chemistry, the reading and writing practices were those of physics, chemistry, biology or geology.

### ***Accessing science text***

The ability to access (expository) science texts is often taken for granted and not explicitly supported in traditional undergraduate science classes. The assumption by lecturers is that students are unwilling to read these texts. The SF course aimed to make explicit for students how to access and decode science texts in a meaningful way; i.e. to make the generic

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structures and discourse patterns in texts clearer to students. Since no overall expository text structure exists, the reader has to approach the reading of expository text by focusing on the coherence of the text (Beck and McKeowan, 1989). This means that the reader's expectations are based on their knowledge of the topic. The latter is problematic for most entry-level students who generally possess an underdeveloped experiential knowledge base. The implication is that there is often little guidance to the reader in order to construct a meaningful text representation.

In the SF course this was addressed in the Accessing Science Text (first semester) and Communicating Science (second semester) modules (see Appendix 1) where the teaching approach is underpinned by the principles proposed by Robinson (1993). His '12 questions approach'<sup>10</sup> is instructive for teaching students the skill of accessing information from expository text, since it demonstrates explicitly the metacognitive skills that an expert reader taps into when trying to make sense of text.

Concept mapping was used to address improved conceptual understanding by using the concept map as a heuristic approach to present graphically students' prior knowledge and to demonstrate to them how to incorporate new knowledge into existing conceptual frameworks (Trowbridge and Wandersee, 1994; 1996; Wandersee, 1990).

### *Genres of communicating science*

Students were introduced to several genres for scientific communication, such as scientific reports, research posters and expository essays. Issues such as literature reviewing, referencing and plagiarism were also discussed. Each task – report, poster or essay – went through an extensive drafting and re-drafting process before final submission.

... people who did not do the SF course, they struggle when doing their scientific reports and they can't communicate well ... they don't talk freely and they don't talk their minds and they sort of even if they have to prepare a poster ..., they don't know how to write a poster well, outline, how to go about collecting data for scientific reports or a poster or presentation in class, so SF help in those places and their communication skills are very bad. (2001)

### ***Learning as identity development through participation***

Students' exposure to 'real-life' scientists and their participation in

authentic inquiry-based investigations, as well as debates and discussions helped them to begin to take on an identity as a scientist.

*Student-designed scientific investigations*

Students conducted their own scientific investigations on a topic of their choice. The aim here was to further develop their conceptual base and appreciation of science as a method of inquiry, as well as to promote an interest in science. One student who decided to conduct research into radioactivity following a presentation by a researcher in the area of nuclear physics, approached the Physics Department at UWC and asked for guidance and equipment to conduct an investigation. He produced an excellent scientific report and presentation at the end of the semester. He had the following to say with regard to how this experience enabled him to realise his calling to do science and that added value to his development:

SFP skills prepared me for the future, as it better prepared me for first year. The Scientific Investigations module was good, the guest lecturers motivated us to come to class and it was something different. I took my scientific investigation to the Koeberg power station and found some interesting results; **I might want to do nuclear physics in the future.**

In the next quote, there is a sense of a student beginning to envisage herself as a scientist, and hence taking on a new identity:

That is, it gave us a 'behind the scenes' look into how scientists work, generate knowledge, it helped me to see that yes, **I could be a scientist despite my background.**

Both quotes illustrate how students – through participating in authentic social practices of science – begin to develop an identity as a person who could become a scientist. This engagement is important, as the higher education environment is often experienced as an alienating space or academic 'no-man's-land', particularly for students for whom the university culture is very different from their own home culture (Mann, 2001; Case, 2008).

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### *Participation in peer communities*

The SF modules were designed to expose students to the nature of science, and develop their ability to take on the discourses of science; strategies such as peer debates and discussions after some reading on a controversial topic (e.g. genetically modified organisms) were used to promote reflection and conceptual development. Students found this an interesting way to learn about science, since the course addressed what they regarded as relevant socio-scientific issues.

This 'student-centred' approach was underpinned by the view that learning is a socially negotiated activity (Vygotsky, 1978) and the result was that peer group members became the sounding-board for ideas. Peers provided feedback on drafts of each others' work and there was a general improvement in their writing. Students were aware of the course aims in terms of their academic development and seemed to view presentation skills and scientific report-writing skills as being part of the social practices of real scientists, and therefore worthwhile activities.

### ***Exposure to scientists and scientific activities***

For many of the SF students, exposure to science and mathematics has been restricted to the confines of the formal classroom (rather than through the forms of informal exposure that more economically advantaged students may have had; such as reading library books, visiting museums, having conversations at home, and watching science programmes on TV). Thus the poor experiential knowledge and lack of exposure to science is a major constituent of educational disadvantage.<sup>11</sup> The SF course provided opportunities for students to develop the relevant background/experiential knowledge for science courses (e.g. by watching documentaries on scientific topics and reading around topics that were topical and at times controversial, such as cloning). The use of the story about the concepts (e.g. natural selection and its constituent concepts such as mutations, variation) during tutorials enabled us to promote reading and writing skills whilst exposing students to the historical development of theory, principles and concepts. Researchers in various disciplines were also invited to speak to the students about their research, thus exposing them to authentic scientific activity.

### **Impact of the SFP**

The impact of the teaching and learning strategies on student learning and academic success can be looked at in terms of:

- Improved self-concept.
- Conceptions of the nature of science and of science learning.
- Developing independent learners.

### ***Improved self-concept***

SFP students were generally grateful for having the opportunity of a 'second-chance' access route to studying science. However, there was an element of alienation (from mainstream science) and frustration with the fact that they had to do their degree over four years. They also had to deal with the 'stigma' associated with their 'foundation student' status, although this seemed to disappear as they realised they were gaining something worthwhile and tangible from the SF course. Student feedback indicated that the reduced workload, academic support and the SF course in general appears to have promoted a better self-concept for most students:

I'm a very positive person and I think nothing would ever stop me going there, yah I still want to do it, that's the only thing for me and I believe if, ... that when you do something that you really want to, you enjoy it, than doing something that you have to do. (2001) [This student has subsequently been accepted into the MBCHB degree]

Although science may initially have seemed alienating to some students, there was evidence of their developing identities as science students and prospective scientists.

### ***Conceptions of the nature of science and of science learning***

Research has confirmed that SFP students have a richer understanding of the nature of science than their mainstream counterparts. This can be expected since discussion around the nature of science was an explicit focus in the SF course. With regards to student views on learning, metacognitive shifts appear to have occurred for most students. Focus-group interviews indicate that students' views on learning have shifted from adherence to a passive, transmission mode of instruction to one where learning is something they 'do' instead of it being done to them.

### ***Developing independent learners***

In the SF course the emphasis shifted from the more traditional 'chalk-and-talk' lectures to employing strategies that promote student interaction, engagement and participation. By providing students with opportunities to develop metacognitive skills, they appeared to assume responsibility for their own learning and improve their work ethic. The SFP students also appeared to be able to transfer their questioning and inquiring skills to other courses. Staff on mainstream courses noted that students who came through the system via the alternative access route (SFP) were particularly bright and hardworking students. This supports the research findings of the SF team.

I think in terms of optimism and the ability to work I'm talking about the students who were with me in the SFP, a lot of them have dropped out umm out of university ... but the (remaining students) that's still there are very strong, and they are competing with everybody, they are getting themselves recognised. (2001)

### **Lessons learnt from the SFP**

The SFP (and the SF course within it) was a successful faculty response to the issues of access and retention of underprepared students in undergraduate science studies. There were, however, a number of drawbacks with this model of academic development. These are outlined next.

#### **The AD initiatives in the SF course were not mainstreamed**

The SFP was structurally separate from the mainstream BSc and the responsibility for foundational provision lay with the SFP staff rather than with the faculty mainstream academic staff. All the foundation provision was located within the (non-credit bearing) SF and the pre-calculus mathematics courses. While this autonomy from the mainstream enabled the adoption of innovative pedagogical practices in these courses, this also meant that the mainstream subject that the students enrolled for in parallel with these courses remained unchanged. As many have argued repeatedly since the 1980s, this marginalised model of academic development is not sustainable – if AD remains the concern of entry-level courses alone, then all that tends to happen is that retention and throughput problems become displaced to higher levels of study. Rather, what is required is a challenge to the traditional educational processes of the mainstream itself.

### **Legitimacy of AD activities**

The SF course was not a traditional generic and decontextualised academic literacy 'skills' course (for a critique of such courses in South African higher education, see Jacobs, 2005, and Boughey, 2002). Rather, viewing academic literacy as a social practice, the course aimed to develop students' academic literacy through engaging with authentic social practices of science. The focus was on inducting them into the Discourse (Gee, 1990) of science. In practice, this meant that all reading and writing activities were embedded in science contexts. But, as Gee reminds us, Discourse is more than just the reading and writing practices of a discourse community, it also entails values, beliefs, ways of thinking, etc. The SF course also made these explicit to students, by overtly focusing on the nature of science and involving students in authentic scientific investigations.

However, a possible limitation of this course was that it was not embedded in one particular science disciplinary context. This meant that students were not interacting with the disciplinary experts of any particular discipline, except perhaps when doing their own scientific investigation. So, although the SF course did aim to uncover and make explicit for students the Discourse of science, it was not embedded in a particular disciplinary context, and drew instead on examples from physics, chemistry, biology and earth science. Kloot, Case and Marshall (2008: in press) raise a similar critique of the University of KwaZulu-Natal's SFP separation from the mainstream disciplines:

This then raises questions about the SFP's stated aim of initiating students into the 'culture of university science'. Although the project may have been educationally sound and the staff on the programme may have been doing their best to expose students to the 'content and patterns of speech peculiar to scientists' it seems rather abstract if students have no contact with mainstream academics.

This separation from the mainstream seemed at times to affect students' perceptions of the legitimacy of the foundational provision in the SF course. Some students questioned the relevance or usefulness of learning to write scientific reports, think about the nature of science or read science text, when these aspects were in fact seldom explicitly drawn on in the 'mainstream' courses they were doing in parallel. This highlighted the

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fact that many dimensions of the Discourse of science were not being explicitly emphasised or valued in the mainstream courses. For example, students wondered why they needed to understand the nature of science and the process of scientific investigation when the mainstream courses focused exclusively on content and the practicals were recipe-based rather than inquiry-based. However, once the students reached their second year of study, they began to really appreciate the value of the SF course.

The implication of this seemed to be the need to embed academic literacy initiatives into the disciplines themselves. However, this raised questions about academics' capacity to implement such curriculum reform. As Moore and Lewis (2003) point out, the sort of institutional strategies needed to implement the National Department of Education's policies, such as foundational curricula, tend to be those requiring AD expertise and specialist education knowledge, for which most mainstream academics lack the capacity. One possible response to this challenge of instituting mainstream curriculum reform has been the model of having mainstream academics working alongside AD specialists (see, for example, Jacobs, 2005).

Many of the challenges and lessons learnt from the SFP were subsequently used to inform the design of the ECP when it was introduced in 2007. In the next section, the ECP is described.

### **The Extended Curriculum Programme**

In 2006, the DoE earmarked significant funding for ECPs, and offered several possible models for providing foundational provision. The Science faculty opted for a model in which the foundational provision would be built into three extended science courses (Physics, Life Sciences and Mathematics), which would run over two years. In this configuration, the SF course no longer existed as a stand-alone course, but the foundational provision of the SF course was integrated into the Introductory Physics and Life Science courses (both of which content-wise were equivalent to the regular first-year course). These courses were therefore designed to provide the foundational provision needed for all undergraduate science programmes or qualifications:<sup>12</sup> Physics (for the mathematical sciences – chemistry, geology, computer science, mathematics and statistics) and Life Science (for the life and medical sciences). The ECP was introduced at UWC in 2007, the structure of which is shown in Figure 2.

**Figure 2: The physical/life sciences Extended Curriculum Programme (year 1–4)**

Academic Year	Modules			
Year 1	Maths 1a (with foundational provisions) 15 credits	Physics/Life Science 1a (with foundational provisions) 15 credits		English for Educational Development and Computer Literacy 30 credits
Year 2	Maths 1b (with foundational provisions) 15 credits	Physics/Life Science 1b (with foundational provisions) 15 credits		Regular subject 30 credits
Year 3	Major 1	Major 2	Elective	
Year 4	Major 1	Major 2		

The two staff members responsible for teaching the SF course were relocated – one to work with the Life Science course, and the other with the Physics course.<sup>13</sup> This new configuration – with the SF course integrated into the Introductory Physics and Life Science courses – meant that some of the drawbacks of the SFP raised above could now be addressed.

Firstly, the responsibility for faculty academic development and foundational provision had shifted towards the discipline and department rather than being the sole responsibility of a separate AD group. Although the ECP courses were located in the discipline departments, oversight for the faculty ECP was the responsibility of the Deputy-Dean for Teaching and Learning and the faculty’s ECP committee (a sub-committee of the faculty’s Academic Planning Committee).

The extent to which mainstream departments have taken responsibility for the ECP courses has depended to some extent on the educational capacity within departments to design and teach foundational curricula. While some departments have employed separate ECP lecturers to design and teach the ECP courses, an alternative model has been to involve mainstream academics in the design and teaching of the ECP.

The second advantage of the ECP configuration is that the academic literacy activities are now more fully integrated into the discipline-content, thus increasing their perceived legitimacy from the perspective of the

students. In the section below, we discuss the key aspects of the SF course that were incorporated into the Physics and Life Science courses. For the sake of brevity, illustrative examples will be taken from the Physics course.

### **Making the nature of science explicit**

A key focus of the SF course had been to make the nature of science explicit to students. While the SF course necessarily talked about the nature of science in a generic sense, the Physics and Life Science courses were able to contextualise this in the context of the particular disciplines, and so many of the learning activities of the SF course have now become embedded in the disciplinary contexts of Physics and Life Science.

For example, the Physics course started with a focus on the nature of science, models and modelling in physics, leading into an exploration of models in atomic and nuclear physics. The AD practitioner and the lecturer collaboratively designed learning activities that looked more overtly at the nature of science (e.g. the tentative nature of knowledge in the context of the development of models of the atom). The AD practitioner's interventions also helped to ensure that the meanings of terms such as 'scientific investigation', 'model', 'law' and 'theory' were not taken for granted by the lecturer, and that an explicit focus on the nature of science ran as a thread throughout the physics content during the year.

This overt focus on the nature of science was also carried over into the Physics practical sessions, which began with discussion and exploration of how scientific investigations are conducted. This is in contrast to the traditional approach of plunging straight into conducting practicals – usually 'cook-book' style rather than more authentically framed inquiry-based practicals.

### **'Thinking like a physicist': the nature of physics as a discipline**

As we have noted earlier, each science discipline has its own particular Discourse which needs to be made explicit to students. In the case of physics, undergraduate students tend to experience physics as a set of unrelated equations to manipulate; while 'expert' problem-solvers begin with a qualitative analysis of a situation, looking at general principles, undergraduate problem-solvers tend to begin with equations. This is often ascribed to the way physics is traditionally taught, with little explicit focus on the conceptual and representational aspects of problem-solving (Leonard *et al.* 1996). Lecturers, as 'insiders' in the discourse, often take for

granted the different representations used in physics, and regard it as self-evident that concepts and principles are the starting point for solving a problem. But this is often not made explicit in terms of what is emphasised in lectures and in assessment.

We have found that Van Heuvelen's multiple representations approach to teaching physics (Van Heuvelen, 1991) is a powerful way to make explicit for students the different verbal, pictorial, physical, graphical and mathematical representations that comprise the disciplinary discourse of physics. Viewing learning as acquiring the discourse of physics implies that students need to be explicitly guided to develop the ability to shift between these multiple representations – a facility which Linder and Airey (2008) term 'discursive fluency'.

### **Making the tacit explicit: Reading and writing science texts**

Both the Physics and the Life Science ECP courses drew on the teaching approaches used in the SF course to help students access science texts. In the Physics ECP course, the AD practitioner was a non-physicist, and so was easily able to identify with the difficulties that students faced in reading their physics textbooks. For example, when students were required to produce concept-maps of a section of their textbook, evaluation of this task revealed that students had great difficulty in discerning the hierarchy implicit in the text between the main concepts/principles, the sub-concepts, and the illustrative examples. Students were shown the ways in which to decode the implicit structure of the physics text by looking at 'cues' in the text construction.

Drawing on the approach of the SF course, the students were introduced to several genres for scientific communication – scientific reports, research posters and expository essays. Issues such as literature reviewing, referencing and plagiarism were also discussed. Each writing task – report, poster or essay – was embedded in the physics classwork or practicals, making explicit aspects that are usually left tacit. The students went through an extensive drafting and re-drafting process before final submission.

### **Learning as identity development through participation**

#### ***Authentic, inquiry-based practicals***

If learning is about accessing a discourse, and thereby taking on a particular identity, then it is important for students to take part in

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authentic disciplinary practices. The SF course focused on developing students' science process skills by involving them in real-life authentic investigations, and this approach was carried over into the ECP. For example, in the Physics course, the practicals were set up to be quasi-authentic and inquiry-based, rather than the more traditional recipe-like first-year practicals. Initially, each practical was spread over two or three weeks so that there was time to explore and make explicit those aspects of doing practicals which are usually taken for granted (e.g. the experimental design, handling equipment, analysing and interpreting data, understanding of measurement and uncertainty, the structuring of a report). In an attempt to model for students an authentic process of scientific investigation, students were not given a set of instructions to follow, but were required to develop their own experimental design and figure out how the equipment worked and how they would collect and present their data. Rather than getting students to write the traditional 'lab report', the focus of the writing was for an authentic purpose and audience (for example: 'Use variations in the value of  $g$  to prospect for oil on the campus and write a report for the client, PetroSA.')

Some of the students also opted to be involved in small-scale research projects in the department during the second semester. These enabled them to participate in the social practices of research groups within the department.

### ***Participation in peer communities***

The participatory approach to learning of the SF course was adopted in the ECP Physics and Life Science courses too. This fostered discussion and debate, which are essential if students are to take on the Discourse of the discipline. In the ECP Physics course, the traditional lectures were replaced by workshop-style classes in which students worked in cooperative learning groups.

### ***Identity formation as a scientist***

As with the SF course, the ECP courses focused on increasing students' exposure to and involvement in the social practices of the disciplines, through visiting speakers, talks, films, etc. For example, in the Physics ECP, we have tried to emphasise to students that there is not one monolithic identity as a 'physicist' (usually the academic/researcher identity), but that there is a range of possible options that may accord with their interests,

aspirations and motivations. We did this by exposing them to a range of speakers who used physics in different ways in their professional capacities (e.g. an astronomer, a nuclear risk analyst from Koeberg nuclear power station, an industrial geo-physicist). For greater exposure to science, we also arranged site visits, made available popular science journals (such as the *New Scientist*) and encouraged students' attendance at general interest seminars in the department.

### ***Identity formation as a critical citizen***

The focus in the SF course on topical and controversial topics for discussion was intended to foreground the social, political, environmental and ethical dimensions of science. The Physics ECP, likewise, focused on providing students with opportunities for 'talking science', and engaging in discussion about socio-scientific issues relevant to their lives and to the community. This is seen as contributing to the student developing an identity as an informed, critical citizen.

### **Impact of the ECP**

Since 2008 was the only the second year of the ECP's existence, evidence of its impact remains limited. Nevertheless, preliminary indicators suggest that it has the potential to make a significant impact on student retention and success in their undergraduate science studies.

### ***Student academic success***

In all the Faculty of Science ECP courses, the pass rates for the ECP students were better than their three-year-stream counterparts. For example, the 2007 Physics ECP class had a pass rate of 72%, as compared to 53% for the equivalent three-year-stream class. In addition to pass rates, we also conducted inventories comparing the understanding of fundamental physics concepts of the ECP students and the three-year-stream students;<sup>14</sup> and the ECP significantly outperformed the three-year-stream students. In 2008, we continued to benchmark the ECP students, now in their second year of study. Preliminary indications – based on class tests in which the ECP students outperformed the three-year-stream students – suggest that they were well prepared for the challenges that lie ahead when they join the 'mainstream' second-year classes.

***Student motivation***

The ECP students in all the ECP courses seem to be more motivated than their three-year-stream counterparts. This is reflected in class attendance figures and the proportion of the class who make use of optional extra tutorials. In the Physics ECP course, over a third of the students voluntarily committed themselves to an undergraduate research training programme, which enabled them to become involved in some small-scale research projects based in research groups within the department.

***Changing mainstream teaching practices within departments***

Within the Science Faculty, the existence of the ECP has undoubtedly raised the profile of teaching and learning issues among mainstream staff members. The monthly ECP sub-committee meetings are attended not only by Heads of Department or representatives of departments who themselves are offering ECP courses, but by others as well. The faculty-based 'Conversations about Teaching and Learning' seminar series, although an ECP initiative, is attracting more and more mainstream lectures to the discussions and seminars.

Within the Physics Department itself, there is some evidence of the ECP having a ripple effect on mainstream teaching practices. One of the major drivers of this is the ECP model adopted by the Department – the ECP teaching is not relegated to a contract lecturer to teach 'on the side', but instead the ECP teaching is seen at the heart of the department's mainstream academic project. In this way, several mainstream Physics academics<sup>15</sup> have been 'co-opted' into the Physics ECP team since its inception. This has resulted in several noticeable changes in teaching practices within the department, including the adoption of more interactive modes of teaching, greater explicit focus on the disciplinary discourse of physics through the use of multiple representations in teaching and assessment, and the modification of first-year practicals to be more inquiry-based. The ECP has also informed discussion about the current second-year course structure, which will be re-structured in 2009 with a more explicit focus on the modelling, 'thinking like a physicist' approach to problem-solving introduced in the ECP, as well as with more interactive teaching and supportive tutorials.

It is still too early to report on the ECP students' entry into mainstream courses, but preliminary suggestions that the ECP may be influencing mainstream teaching practices augur well for the quality of the teaching

and nature of the support that the ECP students may receive in subsequent years.

### **Future challenges for the ECP**

#### ***Constraints on mainstreaming ECP courses***

As noted at the start of this section, the structure of the ECP has shifted the responsibility for AD towards the discipline and department rather than being the sole responsibility of a separate AD group. However, limited funding has made mainstreaming difficult to achieve and some departments have adopted a model whereby a separate staff member on contract teaches the ECP courses. The Physics Department, on the other hand, has resisted the marginalisation of ECP teaching by co-opting several of its mainstream staff members to teach the ECP courses. This arrangement is, however, not sustainable in terms of compromising the resources required for other courses in the department.

An additional constraint, as Moore and Lewis (2003) note, is the educational expertise (and willingness) required of mainstream academic staff for the infusion of foundational provision into traditional mainstream courses. In the case of the Physics ECP, the collaboration between an AD practitioner and the discipline lecturers fostered this infusion of foundational provision into the Physics content. Ideally, it would serve the faculty well to have several such AD practitioners to work alongside mainstream lecturers in assisting with the infusion of foundational provision into their curricula.

Institutional commitment and investment are needed to effectively mainstream the lessons learnt from the ECP into all undergraduate science courses in order to improve throughput and success of students in the faculty.

#### ***Sustaining the infusion of foundational provision***

In the ECP courses, the intention was to seamlessly integrate the foundational academic literacy activities that had previously formed part of the SF course. The assessment on these ECP courses emphasised the interconnection between all aspects of the course – academic literacy skills, experimental skills, understanding of the nature of science and problem-solving skills.

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In the Physics ECP, for example, the test and exams included questions requiring students to read and understand a science text, construct concept maps, demonstrate an understanding of the nature of science, and to apply their understanding of measurement and uncertainty. In promoting this infusion of foundational provision into the discipline courses, the collaboration between the AD practitioner and the lecturers was central (see Jacobs, 2007). The students seemed to experience the academic literacy activities as legitimate and valuable, since they were infused into the disciplinary context and formed part of the formal course assessment. The Physics ECP team has, however, been reminded of how this infusion approach depends critically on human resources and expertise; and when the second half of the ECP course began in 2008 teaching capacity was stretched. This, coupled with the resignation of the AD practitioner, meant that the explicit focus on the foundational, academic literacy aspects of the course was at times compromised. With teaching capacity stretched, the physics lecturers were easily drawn to focus on the physics content, and the time required for developing students' academic literacy – e.g. providing detailed, individual feedback on written drafts – was sometimes inadequate.

### ***Transition to the mainstream second year***

Research on Science Foundations Programmes in South Africa points to the critical transition that students experience when entering the mainstream. There is often a conceptualisation that once the students' 'deficits' have been remedied in the foundational years the rest of the degree structure can remain unchanged. However, it is precisely at the point of transition to the mainstream that students often falter. As Scott, Yeld and Hendry, (2007: 278) note, it is the mainstream teaching itself that is required to change:

The decade of experience with foundation programs had ... shown ... that the curriculum had to be seen as a whole, that foundational intervention had to be reinforced by sound educational practice at higher levels.

In the Physics ECP, we have designed the second year of the ECP course with the transition to mainstream in mind. In the final term of the course, students follow a Problem Bases Learning module, which focuses on

consolidating and integrating the concepts taught over the two-year ECP period, thus attempting to address the fragmented and compartmentalised approach to learning physics common among undergraduate students. The course is taught by one of the mainstream second-year lecturers, and it is hoped that this will help students when they enter the mainstream.

### **Conclusion: The way forward**

In this chapter, we have mapped out the historical trajectory of AD initiatives in the UWC Science Faculty, starting with the ‘infusion’ model of the early 1990s, followed by the creation of a separate SFP (2001–2006), which then was reconfigured into the present ECP in 2007.

Drawing on Boughey’s (2007: 8) analysis of universities’ responses to the construct of ‘disadvantage, it could be argued that the “infusion” model, with its focus on institutional transformation, was informed by a “historical-structural” understanding locating “disadvantage” in structures that act on individuals’. On the other hand, the SFP’s separateness from the mainstream reflected to some extent an understanding of ‘disadvantage’ as located in individuals. Yet it was the separate position of the SFP relative to the mainstream that enabled it to introduce many innovative teaching approaches into the curriculum. As Kloot *et al.* (2008: in press) note regarding this tension:

The more separate the programme, the more opportunity there is for curriculum innovation. On the other hand, a separate programme, in reality, tends to be marginalised and therefore has limited impact on the mainstream which is where the change really needs to happen, especially in terms of the current need for quality graduates in Science, Engineering and Technology (SET).

While the marginality of the SFP allowed for curriculum innovation, it had limited impact on mainstream teaching in the faculty. The new configuration of the ECP – with the infusion of foundational provision – has allowed the incorporation of some of the innovative teaching approaches of the SFP into the more traditional mainstream curricula. The ECP has in many respects taken up the 1990s model of ‘infusion’ once more; and instead of separate add-on courses focused on a student ‘deficit’ model, the ECP has pioneered the infusion of foundational provision into mainstream discipline-based courses in an attempt to address the structural barriers to

student success that exist in the mainstream curriculum.

However, if the ECP is to have sustained and significant impact on mainstream teaching practices, it will require institutional commitment and investment to effectively mainstream the lessons learnt from the ECP into all undergraduate science courses in order to improve throughput and success of students in the faculty. The 'infusion' model of AD of the 1990s needs to be reclaimed – not merely in terms of progressive policy statements on access and retention of students, but in terms of institutional resource allocation and staffing of the ECP.

There are indications that, given the uncertainty of the schooling system, and the fact that the three-year BSc structure is not working for the majority of the students nationally, the four-year BSc degree is likely to become the norm in the future. A four-year structure would allow more flexibility for curriculum planning to meet the needs of the students, moving away from notions of 'fixing' individual students (in a few add-on skills courses or an introductory ECP year or two) towards rethinking the entire undergraduate curriculum. This challenges the UWC Science Faculty to work on how to infuse AD into all undergraduate curricula in order to widen student access and improve throughout the success of undergraduate students.

## **Endnotes**

- <sup>1</sup> Only 5.2% of black African school-leavers in 2003 obtained the grades needed for degree study (Scott, *et al.* 2007).
- <sup>2</sup> The *Directory of Science, Engineering and Technology Foundation Programmes* (Pinto, 2001) comprehensively reviews initiatives at nearly all the tertiary institutions in South Africa.
- <sup>3</sup> As Jacobs (2007) notes, most academic literacy courses at SA universities (and internationally) remain generic and decontextualised.
- <sup>4</sup> Although historically set up as a 'coloured' university in the 1960s, UWC opened its doors to students of all races in the 1980s. This led to student enrolment increasingly significantly, as well as a change in student demographics: the proportion of African students rose from 2% in 1984 to 34% in 1992 (Walker and Badsha, 1993).
- <sup>5</sup> The Higher Education Quality Committee (HEQC) cohort study of the intake of students to the national higher education system in 2000 showed that for three-year science programmes, only about 23% of students completed their degree in minimum time, and only 11%

- of black students completed in minimum time. Moreover, a sizeable proportion of those not graduating in minimum time had actually withdrawn from these programmes (see Scott *et al.*, 2007).
- <sup>6</sup> As Scott *et al.* (2005: 279) note, the 1997 White Paper was significant for the AD enterprise, since it was the ‘first-ever state recognition of equity-oriented developmental work, and just as important, included a commitment to funding equity-oriented provision’.
- <sup>7</sup> Gee’s placement of ‘reading and writing’ at the end of this list of characteristics of a Discourse is significant, emphasising that reading and writing are merely part of what comprises a Discourse. He labels the reading and writing aspects of a Discourse, the (little d) discourse.
- <sup>8</sup> For a more detailed discussion of the distinction between bridging and foundation programmes in undergraduate science contexts, see Grayson (1996) and Pinto (2001).
- <sup>9</sup> New Literacy Studies research emphasises the multiplicity of academic literacies that students encounter in higher education – for example, the disciplinary discourse of physics differs significantly from that of mathematics. Nevertheless, at an introductory level there are certainly some broad generalisations one can make regarding ‘science’; for example, that science is tentative, empirically based and socially and culturally embedded (see, for example, Abd-el-Khalick, Bell and Lederman, 1998).
- <sup>10</sup> Robinson asserts that academic skills such as reading efficiently, writing well and preparing for tests play a part in the success of so-called smart students. However, these are not natural abilities, but they are skills that can be mastered.
- <sup>11</sup> Bourdieu refers to this as ‘cultural capital’ – all the non-material benefits that students from middle-class backgrounds possess by virtue of their background. He argues that the value systems and academic discourse of higher education approximate the discourse prevalent in the homes of middle-class families, and so working-class students are disadvantaged both materially and culturally (see, for example, Bourdieu and Passeron, 1977).
- <sup>12</sup> ‘Qualification’ refers to the formal Ministerially approved qualifications (e.g. BSc Biotechnology).
- <sup>13</sup> In the case of Physics, this AD person was a specialist in biology education, and not a physicist. This serendipitous development allowed us to explore the scenario described by Jacobs (2005), in which AD

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practitioners work alongside discipline specialists in helping students to access a disciplinary discourse.

- <sup>14</sup> We administered the widely-used Force Concept Inventory: the ECP students scored 11% higher on this instrument relative to the three-year-stream students.
- <sup>15</sup> Although Department of Education funding is used to fund two contract ECP lecturers, in practice the ECP courses require far greater staff input. In total, half the mainstream academics in the Physics Department (five of the full-time complement of 10 staff members) have taught part of the ECP courses.

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# *6. Prospective A-Level Mathematics Teachers' Perspectives of the Concept of a Function*

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## **Abstract**

Mathematics educators today seem to agree that mathematics teachers need more than subject matter knowledge in order to teach well. This chapter discusses an investigation of prospective A-Level mathematics teachers' perspectives of the concept of function. These prospective teachers were undergraduate students majoring in mathematics and were about to complete a programme leading to certification as secondary mathematics teachers. A semi-structured interview guide was used to capture the prospective teachers' definitions of a function as well as their ability to use their definitions in the practice of teaching. The main findings of the study were that while the prospective teachers knew the modern definition of a function, they were not able to use the arbitrariness and the univalence properties of functions to distinguish functions from non-functions. The authors recommend that in order to ensure that mathematical concepts such as the function are accessible to as many students as possible, mathematics educators have to provide students with many examples that form the desired concept image not only at the beginning but throughout the whole period of learning. The idea of giving a verbal definition of a function as a list of criteria and expecting students to construct the concept from the definition is a reversal of how mathematical concepts evolve.

## **Introduction**

The issue of knowledge for teaching is not new; it has been discussed for at least two decades. Shulman (1986) pointed out that teaching entails more than simply knowing the subject matter and that it involves transformation of knowledge into a form that learners can comprehend. He concluded that, besides content knowledge and curricular knowledge, teachers needed a third kind of knowledge – which he called pedagogical content knowledge. He suggested that pedagogical content knowledge ‘goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching’ (Shulman, 1986: 9). He argued that teachers have to know and understand more of their subject than other users of the content.

Since Shulman, many educators have attempted to elaborate pedagogical content knowledge (e.g. Ball and Bass, 2004). Among these researchers and authors, there seems to be consensus that:

- Teachers need a special kind of knowledge for teaching.
- For mathematics there is mathematical knowledge for teaching (MKFT), which is knowledge that teachers require in order to teach mathematics well.

Although researchers have not yet come to a consensus as to what exactly comprises MKFT, they all seem to support the ideas of Shulman and colleagues (Ball and Bass, 2004) that for teachers to teach mathematics well, they need to be able to unpack or decompress their mathematics into units that can be accessible to learners. For example, when a function is viewed as a process in which an element  $x$  in the domain is transformed to an element  $f(x)$  in the range, the function is said to be in its decompressed form. However, as soon as an individual starts to think of a function as an object being represented by the symbol  $f$  in which the ideas of the domain and the range are suppressed, the concept of function is said to be in compressed form. At this point a function becomes an object, which can be acted upon. In other words, teachers need not only know how to do mathematics, but should also know how to use the mathematics in practice. Some researchers, drawing on Shulman’s work, have attempted to identify and describe the knowledge required by teachers in order to teach more specific mathematics content areas. For example, Marks (1992) worked on equivalent fractions, while Even (1998) worked on functions.

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Their findings support Shulmans' ideas since they could identify some special mathematical knowledge that teachers of the specific mathematical content areas require in order to teach the specific content well.

In the learning of mathematics, definitions of concepts play important roles. They do not only help in forming concept images, but also have a crucial role in identification tasks involving mathematical concepts (Vinner, 1993). This chapter reports on one aspect of a study that aimed to describe the nature of prospective A-Level mathematics teachers' knowledge for teaching the concept of function at Masvingo State University in Zimbabwe.

Fundamental to the study of mathematics, the concept of a function has been identified as the single most important concept from kindergarten to high school (Dubinsky and Harel, 1992). Eisenberg and Dreyfus (1983) proposed that having a sense for functions is one of the most important facets of mathematical thinking, in that it allows students to gain insights into the relationships among variables in problem-solving situations. Besides advocating for an increased emphasis on the concept of function, reform documents such as the Presidential Inquiry into the Zimbabwean Education System (Government of Zimbabwe, 1999) also emphasised that teachers ought to have a basic understanding of the concept of a function and its use in the growth of mathematical ideas. In an earlier study on the state of mathematics education in Zimbabwean primary schools, Kilborn *et al.* (1996: 131) recommended that:

Teachers must help every student develop conceptual and procedural understanding of number, functions ... and the connections among these ideas.

Despite widespread agreement that the mathematics curriculum should be centred on the concept of function, the complex process of developing a conceptual understanding of the concept continues to be difficult for learners to master. Learners are often unsuccessful at establishing the correct connections between various functional representations. The qualitative interpretation of graphs of functions is especially problematic. Since the learners' mathematical knowledge, their abilities to reason and to solve problems, and their dispositions towards mathematics, are all shaped by teachers' mathematical and pedagogical decisions (Ball and Bass, 2005), this chapter explores prospective A-Level mathematics

teachers' perspectives of the concept of a function. The chapter, which is part of larger study related to prospective A-Level mathematics teachers' knowledge for teaching the concept of function, was designed to answer the following questions:

- What are the prospective A-Level mathematics teachers' perspectives of the concept of function?
- To what extent are prospective A-Level mathematics teachers able to use their definitions of a function in interpreting and making mathematical and pedagogical judgements about learners' solutions to identification tasks involving the concept of function?

### **Theoretical framework**

Kvatinsky and Even (2002) developed a theoretical model for analysing teachers' knowledge for teaching specific mathematical domains. The framework has seven aspects, the first three of which are discussed below. The seven aspects in relation to the concept of a function are as follows:

1. Alternative ways of approaching the concept.
2. Essential features of the concept: What is a function?
3. Different representations of functions.
4. The strength of the concept.
5. Basic repertoire (i.e. specific examples).
6. Different kinds of knowledge and understandings of the concept (conceptual, procedural, intuitive, etc.)
7. Knowledge about mathematics (ways, means and processes in which mathematical concepts such as function are created).

### **Alternative ways of approaching the concept of a function**

Teachers should be familiar with the different possible conceptions of a function. Breidenbach *et al.* (1992) used the terms 'pre-function', 'action', 'process' and 'object conceptions' for describing the different conceptions of a function.

### **Pre-function conception**

An individual is said to have a pre-function conception if he/she gives a response that appears to indicate little or no conception of a function. A typical response in this category is, for example, a function is an equation

(in  $x$ ) with no  $y$  values. Whatever the term means to such an individual, the meaning is not very useful in performing the tasks that are called for in mathematical activities related to functions (Cottrill *et al.*, 1996).

### **Action conception**

An action is a repeatable mental or physical manipulation of objects. Such a conception of a function would involve, for example, the ability to substitute numbers into an algebraic expression and calculate the result. When asked to define a function, an individual with an action conception would give a response which indicates a replacement of a number for a variable and then compute a number where there is no indication of an overall process of transforming a number to obtain another number (Dubinsky and Harel, 1992). It is a static conception in that the subject will tend to think about a function as a one-step algorithm.

### **Process or operational conception**

Operational or the process conception occurs when a person refers to a function as a process rather than an object. The process conception of a function involves a dynamic transformation of quantities according to some repeatable means that, given the same original quantity, will always produce the same transformed quantity. An individual with a process conception of a function is able to think about the transformation as a complete activity beginning with objects of some kind, doing something to these objects, and obtaining new objects as a result of what was done (Dubinsky and Harel, 1992). Such an individual is also able to combine a process with other processes, or even to reverse it. For instance, a function as a process is determined as a whole by input-output, regardless of the internal procedure of computation. Thus the functions  $f(x) = 2x+2$  and  $g(x) = 2(x+1)$  are one and the same as processes even though the arithmetic procedures to compute them have a different sequence of operations. The intermediate stage(s) intimate how (one or more) specific procedures become seen as a single process without needing to carry out the intermediate steps.

### **Object or structural conception**

Seeing a mathematical entity as an object means being capable of referring to it as if it was a real thing. It also means being able to recognise the idea at a glance and to manipulate it as a whole without going into details

(Sfard, 1991). A function is conceived as an object if it is possible to perform actions on it – in general, perform actions that transform it. It is possible to ascertain whether an individual has constructed an object conception of a function by the way that individual talks about or defines a function. A function when conceived as a set of ordered pairs rather than as a computational procedure is such an abstract object.

### **Proceptual conception**

Tall (1992) considers the pre-function, action, process and the object conceptions of a function as representing increasing levels of understanding a function. After the object conception, Tall added the proceptual conception to indicate a conception of a function in which an individual is flexible enough to move back and forth between the process and the object conceptions as required by the task at hand.

### **Essential features of the concept: What is a function?**

According to Kline (1976) the concept of a function originated when Galileo (1564–1642) proposed a programme for the study of motion. The investigation of relations between two varying quantities had been fundamental in arriving at the concept of a function. With the analytical geometry of Descartes (1637), curves described by motion or formula referring to motion rather than by construction were included in the investigations and relations representable in algebraic expressions and their graphs were now accepted as mathematical objects. The invention of calculus reinforced the trend of thinking. Over the next two centuries, Euler, the Bernoullis and other mathematicians developed calculus to deal with physical problems. For these mathematicians a function was an analytic expression representing the relation between two variables with its graph having no corners. This is usually referred to as Euler's definition. Any attempt to widen the class of functions was not readily approved, mainly because the calculus courses did not require any more sophistication than the classical definition. A survey of problems and a pedagogically accepted theory for a first course in calculus shows that Euler's definition covers all the functions used or required in that course (Ponte, 1990). In fact throughout the entire calculus courses, one never confronts a situation where one has to use the modern definition of function. However, a student retains a concept only if it is used in the course (Even, 1998). If only its particular form is used, the student

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unconsciously accepts the particular form as the definition. That is why, at the termination of a calculus course, the student understands functions as a smooth relation between two varying quantities.

During the period 1720 to 1820, a new subject, Analysis, in which the concept of a function was central, began to take form in the field of mathematics. Prior to this, Calculus seemed to be the mathematical course that most affected how the concept of function was defined and applied. The modern definition of function was introduced by Dirichlet to study, not calculus, but more advanced concepts of metric space and topology. Dirichlet (in Kleiner, 1989: 291) redefined a function as follows:

$y$  is a function of  $x$  if for every value of  $x$  defined on the interval  $a < x < b$ , there corresponds a definite value of the variable  $y$ . Also, it is irrelevant in what way this correspondence is established.

Dirichlet's definition of a function was still defined on a set of real numbers.

With the introduction of topology it was realised that the properties of a function depend on the structure of the set on which it is defined and where it takes its values. This led to the concepts of domain and range. From 1900 to 1920 concepts such as metric space, Hilbert space and Banach space were introduced. This development led to new definitions of a function based on arbitrary sets, and not just sets of real numbers. Boubarki, a well-known proponent of abstract algebra, introduced a set-theoretic definition that eventually affected the school mathematics curriculum for many years. In 1917, Carathéodory defined a function as a rule of correspondence between two sets, and later Mona (1972) noted that it is a subset of the Cartesian product of sets. In 1939, Bourbaki offered the following definition of a function, commonly known as the modern definition of a function:

Let  $E$  and  $F$  be two sets which may or may not be distinct. A relation between a variable element  $x$  of  $E$  and a variable element  $y$  of  $F$  is called a functional relation in  $y$  if, for all  $x$  in  $E$ , there exists a unique  $y$  in  $F$  which is in the given relation with  $x$ .

We give the name of function to the operation which in this way associates with every element  $x$  in  $E$  a unique element  $y$  in  $F$  which is in the given relation with  $x$ ;  $y$  is said to be the value of the function at the element  $x$ , and

the function is said to be determined by the given functional relation. Two equivalent functional relations determine the same function. (in Kleiner, 1989: 299)

Bourbaki also gave the well-known and textbook-published definition of a function as a set of ordered pairs (the product  $\text{ExF}$ ).

The modern definition expanded the old definitions to include many relationships not previously considered as functions, i.e. relations defined on split domains, discontinuous functions, functions with a finite number of exceptional points, relations defined by a graph, relations composed of arbitrary correspondences and relations defined by more than one rule. It is important to note, too, that the definition of function as an expression or formula representing a relation between variables is adequate for calculus or a pre-calculus course. The definition of a function as a rule of correspondence between elements is useful when studying Analysis, and a set theoretic definition with domain and range is required in studying topology. Since a small percentage of school students eventually studies analysis and topology, the set theoretic definition should be postponed at the beginning of these courses and a simple and easily understandable definition should be taught at the elementary level. The history of the notion of function shows that the concept had been conceived operationally long before its structural definitions and representations were invented. In any case, as Freudenthal (1983) pointed out, two essential features of the modern concept of a function have evolved: arbitrariness and univalence.

The arbitrary nature of functions, as conceived in the modern definition, refers to both the relationship between the two sets on which the function is defined and the two sets themselves. The arbitrary nature of the relationship means that functions do not have to exhibit some regularity, be described by any specific expression or particular shaped graph. The arbitrary nature of the two sets means that the functions do not have to be defined on any specific sets of objects; in particular, the sets do not have to be sets of numbers. For example, the sets could be composed of a group of symbols, mathematical operations or functions. Whereas the arbitrary nature of functions is implicit in the definition of a function, the univalence requirement, that for each element in the domain there be only one element in the range, is stated explicitly.

As the history of the development of the concept of a function shows, univalence was not a requirement at the beginning. The univalence

condition requires that for each element in the set  $E$ , called the domain of the function, there is associated only one element of  $F$ , called the range of the function. Without the univalence requirement, higher-order differentials were difficult, if not impossible, to distinguish based upon a distinction of the independent and dependent variable involved. Therefore, the requirement of univalence allowed mathematicians to overcome the difficulties of multi-valued symbols and kept analysis manageable.

Most theories of student development of the concept of a function focus on the links between action, process and object-oriented conceptions. One such action-process-object theory of conceptual development of mathematical concepts is Dubinsky's (1991) Action, Process, Object and Schema (APOS) theory of concept development. The APOS theory states that a mathematical concept is first conceived as a process, before it is conceived as an object. The theory suggests that in the development of a mathematical concept a learner first performs actions on already existing objects and interiorises these actions to give processes. These processes are then encapsulated to form new objects; and these actions, processes and objects are built into a wider cognitive schema. In the light of the above analysis, a model of learning the concept of a function can be refined along similar lines. If the conjecture on operational origins of the concept of a function is true, then there must first be a process performed on the already familiar objects (in the case of the function the objects to be manipulated would be a pair of variables where one set is dependent on the other), then the idea of turning this process into an autonomous entity should emerge and finally the ability to conceive a function as an integrated object-like whole must be acquired.

The above scheme of a historical development of the concept of a function is consistent with the psychological theories of the development of mathematical concepts in general. Historically, the concept of a function was conceived operationally long before the structural definitions and representations were formulated. Similarly, the psychological theories consider the structural conception of a function as an extension of the action-oriented conception with the process conception as an intermediary conception between the two conceptions.

### **Different representations of the concept of function**

Work with functions, as with any other mathematical topic, is conducted via different representations such as table of values, formulae, graphs, set

diagrams, function box and set of ordered pairs.

Familiarity with different representations and ability to translate and form linkages among them creates insights that allow a deeper, more powerful and more complete teacher understanding of the concept of a function (Kyvatinsky and Even, 2002). Thompson (1994) remarked that the core concept of a function is not represented by any one of what are commonly called multiple representations of functions, but instead our making connection among representational activities produces a subjective sense of invariance.

## **Procedure**

The participants in this study were six undergraduate students majoring in mathematics with the intention of completing a programme leading to certification as secondary-school mathematics teachers. At the time of study, the prospective teachers had completed the following university mathematical courses: Calculus I, Linear Algebra, Analysis and a course titled Introduction to Higher Mathematics which focused on formal proofs in advanced mathematics. In addition, the prospective teachers had done a high-school mathematics methods course that sensitised prospective teachers on how secondary mathematics could be taught more effectively.

A semi-structured interview guide was used to capture the prospective teachers' definitions of a function as well as their ability to use these definitions in the practice of teaching the concept. The above framework of teacher knowledge of the concept of a function was used as a tool for assessing teacher knowledge for teaching the definition of the concept.

## **Results**

### **Prospective A-Level teachers' initial and alternative definitions of a function**

In Item 1 the prospective A-Level teachers were asked to first give a definition of a function, which they would teach their A-Level class, and then an alternative definition that might help a student with difficulties. Table 1 shows that the initial definitions of a function, which the A-Level teachers would teach their learners, are versions of the new formal definition. Ironically these versions of the modern definition of a function are not appropriate for the A-Level class since the modern definition was

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developed to make Analysis and Topology manageable. Although the new formal Bourbaki definition of a function is too abstract for high-school students, the same definition is cited in the Zimbabwean A-Level mathematics syllabus and in most A-Level mathematics textbooks used in Zimbabwe. Markovits, Eyton and Bruckheinner (1988) made similar observations in their study of US high-school mathematics curriculum.

Also, the initial definitions given by these prospective teachers seem to indicate that these teachers had a structural view of a function. To them a function was a formula (Alice), a set of ordered pairs (Ben), a correspondence or a dependence relation (Edith and Fari).

In their alternative definitions of a function for the student with difficulties in understanding the first definition, the prospective teachers shift from a structural view of the concept of a function to an operational view suggesting that the prospective teachers think that the process view of a function is more comprehensible to the A-Level students than the structural view of the concept. While the initial definitions given by all the prospective teachers portray the impression that they have a structural understanding of a function, their alternative definitions either regard a function as a process that takes a number, does certain things to it and gives back a result or an output (Alice, Ben and Chipu); or that they identify a function with its representation such as an equation or an algebraic expression (Daniel, Edith and Fari). Euler, a renowned mathematician, seemed to have had a similar conception of a function since he too referred to functions as 'analytical expressions' (Malik, 1981). The tendency to identify a function with its representation (such as an equation or an algebraic expression) is referred to by Sfard (1991) as a pseudo-structural conception of a function. One possible reason why prospective teachers would develop such a conception is that the examples used to illustrate and work with functions in their calculus courses are exclusively functions whose rule of correspondences is given by a formula. The order in which the prospective teachers gave their definition of a function is a reversal of the order the concept of a function developed historically and the psychological explanation of the development of the concept. Although the historical and the psychological development of the concept shows that a function is conceived operationally before it is conceived structurally, the prospective teachers prefer to start by teaching the structural definition before the operational definition.

**Table 1: Prospective A-Level teachers' initial and alternative definitions of a function**

Student	Initial definition	Alternative definition
Alice	A function $f$ from a set $X$ to a set $Y$ is a formula that assigns to each element $x$ in $X$ a unique element $y$ in $Y$ . The set $X$ is called the domain of $f$ . The set of corresponding elements $y$ in $Y$ is called the range of $f$ , e.g. $y = \sin x$	An <b>operation</b> done on certain numerical values of $x$ that assigns to every value of $x$ a value of $y = f(x)$ – it's like – given a group of numbers you perform some operation on the numbers. The operation you do is called a function.
Ben	A function $f$ from set $X$ to a set $Y$ is a rule that assigns to each element $x$ in $X$ a unique element $y$ in $Y$ , e.g. $y = 2x + 4$	A <b>process</b> that can be performed on any number and is represented in algebraic form using $x$ as a variable.
Chipo	A function is a dependence relation between two variables which can be described by a formula or an equation.	A mapping where one $x$ value is mapped to only one $y$ – value. The mapping is done by substituting the $x$ value in a given equation/formula to get the $y$ value.
Daniel	A function consists of three objects: two non-empty sets and $y$ and a rule $f$ which assigns to each element $x$ in $X$ a single fully determined element $y$ in $Y$ , e.g. $f(x) = x^2 + 2x$	A function is an equation which has variable inputs, process the inputted number and gives an output, e.g. $Y = x^2$ or $y = \sin x$
Edith	A function is any correspondence between two sets that assigns to every element in the first set exactly one element in the second set.	A mathematical expression or equation that gives a connection between two factors. One can substitute the first factor to get the second factor $y = x$
Fari	A function is a relationship based on a certain algebraic formula in which one set of variables depends on another set of variables. The dependent variable $y$ is said to be a function of the independent variable $x$ if for every value of $x$ there is a corresponding value of $y$ .	An expression that gives a range of answers with different values of $x$ , e.g. $y = x^2 - 1$

### **Operability of the definition of a function**

The second interview question focused on the operability of the definition of a function by the prospective A-Level mathematics teachers. A mathematical definition is said to be formally operable for a given teacher if that teacher is able to use it in creating or reproducing a formal argument (Tall, 1992). The definition of a function is operable for a given teacher if s/he can use the properties outlined in the definition in assessing the correctness of pupils' responses to tasks involving the concept of function. The definitions given by the prospective teachers fell in one of the four categories. Below are the four categories of the definition of function and some of the prospective A-Level teachers' responses to pupils' answers to some hypothetical identification tasks involving the concept of a function.

#### ***Category 1: A function as a rule of correspondence***

Two of the prospective A-Level teachers' definitions of a function fell under this category. Prospective teacher Ben defined a function as follows:

A function  $f$  from set  $X$  to a set  $Y$  is a rule that assigns to each element  $x$  in  $X$  a unique element  $y$  in  $Y$ .

Prospective teacher Daniel's definition was:

A function consists of three objects: two non-empty sets  $X$  and  $Y$  and a rule  $f$  which assigns to each element  $x$  in  $X$  a single fully defined element  $y$  in  $Y$ .

The above definitions eliminate the possibility of an arbitrary correspondence since a rule and an arbitrary correspondence are contradictory. A rule is expected to have some regularity, whereas a correspondence may be arbitrary. The aspect of a rule was dominant in both definitions. The dominant idea of a rule was also expressed by the two teachers in their responses to whether  $\{(1,10); (2,20); (3,31)\}$  was a function or not. They felt that the set was not a function since a 'rule which connects the  $x$ -coordinate and the  $y$ -coordinate cannot be found' (Teacher Ben). The following conversation illustrates how dominant the idea of a rule was in prospective teacher Ben's definition of a function.

- Researcher: What changes would you make to the set of ordered pairs in order to come up with a function?
- Teacher Ben: The last ordered pair should be (3,30).
- Researcher: What would be your reason to consider the new set of ordered pairs a function?
- Teacher Ben: The ordered set would be a function since there would be a rule which connects the x-coordinate with the y-coordinate.
- Researcher: What would be the rule? Can you express it in your own words?
- Teacher Ben: In this case the rule is: multiply the given input  $x$  by 3 in order to get the corresponding output  $y$ .

The emphasis on the rule was also evident in teacher Ben's response to what he thought would be the conditions which had to be fulfilled if the two sets of ordered pairs are to represent the same function.

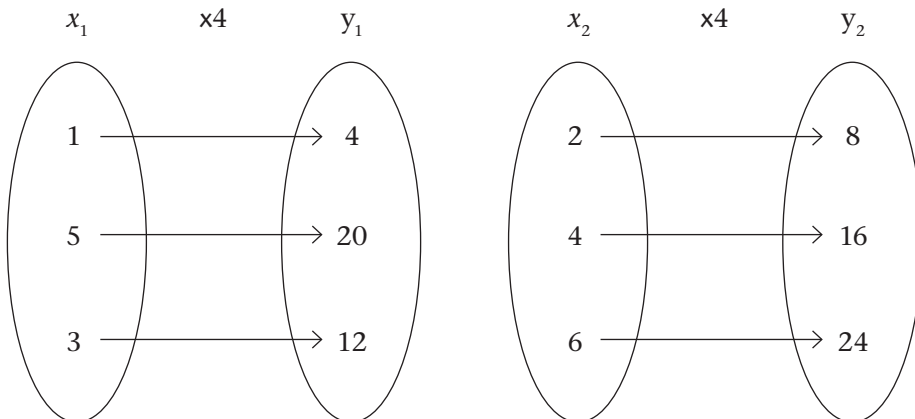
- Researcher: Do the two sets of ordered pairs  $\{(1,4);(5,20);(3,12)\}$  and  $\{(2,8);(4,16);(6,24)\}$  represent one and the same function, or not?
- Teacher Ben: Yes, they represent the same function.
- Researcher: Can you justify your answer?
- Teacher Ben: In each case the  $x$  and the  $y$  coordinates are connected by the same Rule, which can be written algebraically as ... so the two sets of ordered pairs represent the same function.

Since he places undue emphasis on the rule, Teacher Ben thinks the two sets of ordered pairs represent the same function although the two sets of ordered pairs do not represent the same function. The equality of functions depends upon the domains being equal, the ranges being equal and the actions being equal. Equality of functions do not require that the 'rules' should be equal. For instance, and where  $f: \mathfrak{R} \longrightarrow \mathfrak{R}$  and  $g: \mathfrak{R} \longrightarrow \mathfrak{R}$  and where  $f(x) = \max(-x,x)$  and  $g(x) = |x|$ , is one and the same function, although it can be defined by two different rules.

Prospective teacher Daniel did not consider the two sets of ordered pairs as representing the same function. When asked to give reasons for his answer, teacher Daniel re-represented the functional relationship using

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set diagrams to obtain:



Pointing at the sets, teacher Daniel remarked that:

... the corresponding sets are not identical ... you see,  $X_1$  and  $X_2$  variables are different ... the same applies to the  $Y_1$  and  $Y_2$  variables ... So the two sets of ordered pairs do not represent the same function although the rule happens to be the same

Researcher: How best can you describe the rule?

Teacher Daniel: The rule can be represented by the algebraic formula  $y = 4x$

Prospective teachers Ben and Daniel used the words 'rule' and 'function' synonymously. These two teachers could not use their definitions to distinguish functions from non-functions. For example, teacher Ben classified the piecewise function

$$f(x) = \begin{cases} x + 2 & \text{for } x \leq 1 \\ x^2 & \text{for } > 1 \end{cases}$$

as a non-function since it had 'two rules'. However, Ben classified the function

$$f(x) = |x| = \begin{cases} x & \text{for } \geq 0 \\ -x & \text{for } x < 0 \end{cases}$$

as a *bona fide* function. Although Ben considered functions as defined

by rules, he changed his behaviour when confronted with the modulus function. The modulus function was regarded as a function on the basis of familiarity with it.

### **Category 2: A function as a correspondence**

Prospective teacher Edith defined a function as: 'Any correspondence between two sets that assigns to every element in the first set exactly one element in the second set.' This definition is referred to as the Dirichlet–Bourbaki definition. Again, prospective teacher Edith gave a definition of a function that is found in most Analysis textbooks. To avoid the term 'correspondence', one may talk about a set of ordered pairs such that no two pairs have the same first member. The correspondence in the Dirichlet–Bourbaki definition is arbitrary and need not be defined by a rule. However, although prospective teacher Edith gave the Dirichlet–Bourbaki definition of a function, she did not use the arbitrariness and univalence properties of the definition of function in evaluating the correctness of pupils' responses to the hypothetical identification tasks. Prospective teacher Edith felt that the correspondence was defined by a definite rule as evidenced in the following extract:

Researcher: You are saying a student who says 'a correspondence that associates  $-1$  with each negative number,  $+1$  with each positive number, a  $3$  with zero is not a function' is correct. Why do you think the student is correct?

Teacher Edith: It's not just a single function. There are three functions. One of them gives  $-1$  for all negative numbers; the second gives  $+1$  for all positive numbers and the third one gives a zero when the input is  $3$ .

Researcher: Do the following functional representations  $f(x) = \max(-x, x)$  and  $g(x) = |x|$  define the same function or not? Give reasons for your answer.

Teacher Edith: No, they do not represent the same function since the rules of correspondence are not the same.

Teacher Edith seems to think that the rule of correspondence is unique. Thus, to her  $f(x) = \max(-x, x)$  and  $g(x) = |x|$  represent two different functions.

Also, if the correspondence between the numbers looks arbitrary, teacher Edith speaks of infinitely many functions, since for her each 'element would have its own rule of correspondence'.

**Category 3: A function as formula or an equation**

Teacher Alice defined a function as:

A function  $f$  from a set  $X$  to a set  $Y$  is a formula that assigns to each element  $x$  in  $X$  a unique element  $y$  in  $Y$ .

The set  $X$  is called the domain of  $f$ . The set of corresponding elements  $y$  in  $Y$  is called the range of  $f$ .

Teacher Alice's alternative definition of a function was:

An **operation** done on certain numerical values of  $x$  that assigns to every value of  $x$  a value of  $y = f(x)$  – it's like – given a group of numbers you perform some operation on the numbers. The operation you do is called a function.

What is evident from teacher Alice's definitions is that for her there is no difference between the idea of a function and the representation of the idea. Teacher Alice tends to identify a function with the mathematical representation (i.e. the formula) of a function. Such a conception of a function is referred to by Sfard (1991) as a pseudo-structural conception of a function. Teacher Alice seems to possess a process view of functions as verified by her consistent reference to functions as entities that accept inputs to produce outputs where the only possible inputs and outputs are numbers. As a result, she doesn't consider the determinant function, in which every square matrix is mapped to a unique number, as a bona fide function. Teacher Alice's examples of functions were only the special functions, such as linear, quadratic and trigonometrical functions.

**Category 4: A function as dependence relation**

The word 'function' was used by prospective teachers Chipu and Fari to suggest a relationship or a dependence of one quantity to another, as illustrated below:

Teacher Chipu: A function is a dependence relation between two

variables which can be described by a formula or an equation

Teacher Fari : A function is a relationship based on a certain algebraic formula in which one set of variables depends on another set of variables. The dependent variable  $y$  is said to be a function of the independent variable  $x$  if for every value of  $x$  there is a corresponding value of  $y$ .

Unlike prospective teachers Ben and Daniel, who regarded a function as a rule, for prospective teachers Chipu and Fari a function is not just a rule but a relationship between two sets of variables where the relationship is described or represented by means of an algebraic formula or an equation.

It is true that a function is a relationship in which each independent variable is matched to a unique dependent variable. The two definitions given by the two prospective teachers are silent about this important property of mathematical functions. As a result, the two prospective teachers regarded an equation of a circle as representing a function. A probable reason why these teachers regarded an equation of a circle as a function might arise from the use of language in the mathematics classroom. Many authors (e.g. Zill, 1999) still use the term 'implicit function' to describe equations which can be differentiated by a process known as implicit differentiation.

Vinner (1993) drew attention to two modes of the use of definitions – the everyday use and technical mode required in formal reasoning. Definitions given by the prospective teachers Chipu and Fari suggest that these two teachers are using the word 'function' in the literal sense and not in the more restrictive mathematical sense. Although mathematical language builds on the existing structure and logic of common language, there is sometimes a mismatch between the use of words in the ordinary language and the mathematical language. In everyday usage the word 'function' is often used to suggest a relationship or a dependence of one quantity on another; whereas in mathematics the word 'function' has a similar meaning but slightly more specialised interpretation.

All six prospective teachers gave acceptable definitions of a function. The participants' definition or explanations of a function were categorised as acceptable if they made reference to:

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- The arbitrary nature of functions.
- The univalence property of functions, i.e. the uniqueness of the image of each element in the domain.
- That all elements in the domain have an image in the range.

The arbitrary property of functions implies that functions do not have to exhibit some regularity or be described by any specific expression or particular shaped graph. The arbitrary nature of the two sets means that functions do not have to be defined on any specific sets of objects – in particular, the sets do not have to be sets of numbers. Just like 18th- and 19th-Century mathematicians, the prospective teachers still think that functions are defined on sets of numbers. As a result, they all think that a mapping, which maps all square matrices to their corresponding determinants, is not a function. Their reasons for considering the determinant function as a non-function were:

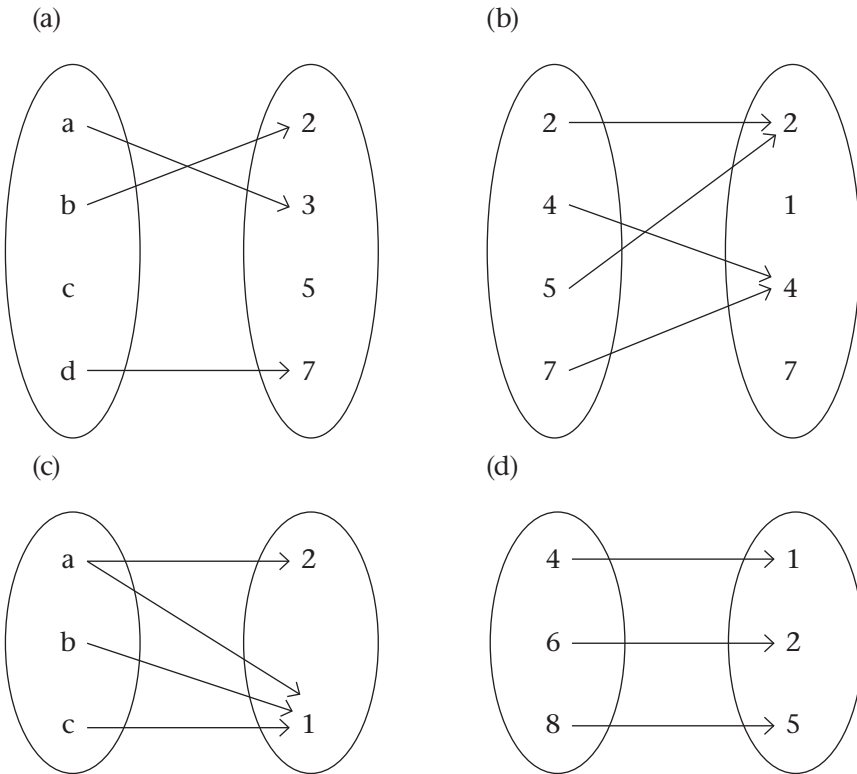
- ... it would not be possible to plot matrices against their determinants since the domain of a function should be a set of real numbers. (Teacher Alice)
- ... there is no equation in which you can substitute a matrix to get a number. (Teacher Chipso)
- ... the strategies (rules) for obtaining the determinant of a matrix depend on the order of the matrix – e.g. for a 2 by 2 matrix the determinants equal to the difference between the product in the leading diagonal and the product of the elements in the other diagonal ... you need a different strategy to evaluate the determinant of a 3 by 3 matrix. (Teachers Ben and Daniel)

The last response above suggests that prospective teachers Ben and Daniel also think that the correspondence between elements in the domain and the range should be defined by a specific rule, whereas the correspondence could be arbitrary.

The univalence requirement that for each element in the domain there be only one element in the range is stated explicitly in the modern definition of a function. All six prospective teachers seem to have little or no understanding of the use of quantifiers; i.e. the phrases 'for every element' and 'there exists only one element' which make the univalence

of functions explicit. Although these quantifiers were explicitly stated in the prospective teachers' definitions of a function, they did not use these quantifiers as criteria for checking whether a given mathematical object was a function or not. For example, the prospective teachers were given the following different representations of functions in isolation and were asked whether or not the representations were of functions.

Set diagrams



Formulae

(a) where  $f: \mathfrak{R} \rightarrow \mathfrak{R}$  and  $g: \mathfrak{R} \rightarrow \mathfrak{R}$  where  $f(x) = \sqrt{x}$

(b) where  $g: \mathfrak{R} \rightarrow \mathfrak{R}$  where  $f(x) = x^{-1}$

In the interviews the prospective teachers were asked to explain why they considered or did not consider the above as functions. The following

responses show that the prospective teachers did not always use the universal quantifier 'for every element in set X' to distinguish functions from non-functions, especially when the functions are represented algebraically.

- a is not a function because there is an element  $d$  left in the domain.
- b is a function because for every element in the domain there is an element in the co-domain.
- c is not a function because there are two values of  $a$ .
- d is a function because for every element in the domain there is an element in the range.

However, all the prospective teachers regarded

$$f: \mathfrak{R} \longrightarrow \mathfrak{R} \text{ where } f(x) = \sqrt{x} \text{ and}$$

$$f: \mathfrak{R} \longrightarrow \mathfrak{R} \text{ where } f(x) = x^{-1}$$

as functions, even though not all elements in the respective domains have images in the corresponding co-domains. In the case of  $f: \mathfrak{R} \longrightarrow \mathfrak{R}$  where  $f(x) = \sqrt{x}$  the negative numbers in the domain have no images in the co-domain, while the second mapping would only be a function if zero is excluded from the domain.

## **Conclusion**

The findings of the study show that the six prospective teachers do not have a deep understanding of the concept of a function, despite the fact that they have studied mathematics at university level. They seem to have a process conceptualisation of a function. They view a function as a repeatable mental manipulation of objects where the only manipulable objects are numbers. It is generally expected that high-school treatment of the function moves student understanding of it from the action conceptualisation to that of a process conceptualisation, the interiorisation of action, so that the total action can take place entirely in the mind of the learner, and finally to the object conceptualisation which is the encapsulation of the process in its totality. Five of the six prospective teachers came up with the modern definition of a function that might suggest that the prospective teachers view a function as an object. However, the results seem to indicate that reproducing the modern definition of a function from memory does not guarantee a clear understanding of a function. The prospective teachers

do not use the definition of a function, which they would have memorised to assess the correctness of the learners' responses to identification tasks involving the concept of function.

Knowing mathematical definitions for teaching requires more than learning mathematically acceptable definitions in various mathematical courses. Being able to reproduce the modern definition of a function is not enough. What is needed is the ability to understand and work with definitions in classrooms, with pupils, treating them in a way that respects the role definitions play in doing and knowing mathematics. Knowing how definitions function and what they are supposed to do, together with knowing a well-accepted definition in the discipline, would equip teachers to develop a definition of a function that has integrity and is also comprehensible to students.

The claim about the developmental precedence of operational conception over structural conception implies that certain kinds of instructional actions, however natural and legitimate in the eyes of the teachers, should in fact be carefully avoided. Two didactic principles can be formulated regarding the things that should not be done.

First, new concepts such as the concept of a function should not be introduced in structural terms. Dubinsky's (1991) model of concept formation implies that it would be of little or no avail to throw unfamiliar abstract objects upon students without giving them time and means to prepare them for the structural conception by building a sound operational base.

Second, a structural conception of a function should not be required as long as the students can do without it. Since the structural conception of a function develops when a learner performs higher-level processes on functions where each of the functions is treated as an integrated whole in its own right (e.g. combining functions which form a Hilbert Space), the A-Level students should not be taught the modern structural definition of a function. For example, as long as Analysis concepts appear nowhere in the A-Level Calculus course, the student can do quite well in the Calculus courses with an operational conception of function alone. An operational conception – namely, viewing a function as a process – is sufficient for dealing with differentiation and integration. Although the undergraduate students are taught the structural modern definition of a function in their Analysis course, there is a need to inform them that introducing the concept of a function set theoretically as a particular kind of relation to an

A-level class is scarcely justified from both didactical and epistemological points of view.

At tertiary level it is important for mathematics educators to provide prospective mathematics teachers with a broad spectrum of ways of giving functions, speaking about functions (e.g. mappings, transformations, etc.) and representing functions, in order to prevent exclusive identification by students of any one of these with functions. Students should be given an opportunity to acquire certain flexibility in using these modes of expression and representations. Currently the practice at tertiary level is to introduce new concepts such as the function to students through definitions in the hope that students would construct the concept through deduction. However, students do not necessarily use definitions when deciding whether a given mathematical object is an example or non-example of the concept (Vinner, 1993). The idea of giving a verbal definition as a list of criteria and expecting students to construct the concept from the definition is a reversal of how mathematical concepts evolve. In order to ensure that mathematics is accessible to as many students as possible, mathematics educators have to provide students with many examples that form the desired concept image – not only at the outset, but throughout the entire period of learning.

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# *7. Promoting the Learning of Mathematics: On the Use of Learning Styles in a Distance Education Calculus Course*

Chipo Tsvigu, Trygve Breiteig, Jan Persens and Joyce Ndalichako

## **Abstract**

In this chapter we argue that one way to enhance access to mathematics in a distance-education environment is to facilitate teaching of the subject matter in a way that is congruent with learners' learning styles. We conjecture that some difficulties with calculus concepts experienced by distance education students may stem from mismatches between the students' learning styles and the ways the materials are presented to them. We thus advocate for consideration and addressing of learning styles needs in calculus learning materials to improve learning. We draw substantially on the Felder–Silverman Learning Styles model. In the chapter we also zero-in on alternative approaches of profiling students' learning styles.

## **Introduction**

Internationally, distance education is playing a vital role in the provision of higher education. The major goal of distance education is to make education accessible to those who, for various reasons, don't have the opportunity to attend traditional, conventional institutions of learning. Although we find distance education programmes in most sub-Saharan countries, it is noticeable that there are only a small number of well-established distance-education universities, such as the University of South Africa (UNISA) in South Africa, the Open University of Tanzania (OUT)

in Tanzania and the Zimbabwe Open University (ZOU) in Zimbabwe. The generally small number of established distance education institutions of higher learning within the region is an indicator of the marginalisation of distance education. However, the huge student enrolments in the distance education institutions emphasise that distance education is a necessity, and has a significant role to play in facilitating access to education.

Once a student is enrolled in a distance education institution, the responsibility of learning rests with the student. The responsibility to enable the learner to access the required subject matter rests squarely with the institution. A well-designed, instructional package facilitates student learning. Distance educators are therefore faced with the challenge of making the subject matter of the discipline accessible to their learners. As in other disciplines, distance educators for mathematics and related courses face the challenging task of making mathematical knowledge accessible to learners – even more so, given the nature of distance education where learners are ‘quasi-separated’ from the teacher and from each other (Keegan, 1990), and the fact that research tends to indicate that learners experience difficulties in understanding some mathematical concepts (Bezuidenhout, 1998, 2001; Cornu, 1991; Dalby, 2001; Dorier and Sierpinska, 2001; Eisenberg, 1991; Ferrini-Mundy and Graham, 1994; Orton, 1983; Robert and Speer, 2001; Tall, 1993). We would argue that one way to enhance this epistemological access is for the responsible institution to facilitate teaching of the subject matter in a way that is congruent with learners’ learning styles. The role of individual learner characteristics, and individual learner differences in terms of learning styles, is an important aspect to consider when contemplating the design, development or improvement of distance education instructional course materials. However, if incorporated in the instructional materials, the learning styles can be used as a resource for promoting student learning in a distance education environment.

### **What is learning style?**

Research on student learning suggests that individuals receive, perceive and process information differently (Claxton and Murrell, 1987; Felder, 1993; Felder and Henriques, 1995; Felder and Silverman, 1988; Logan and Thomas, 2002; Novin, Arjomand and Jourdan, 2003; Riding and Sadler-Smith, 1992). For instance, some students have strong preferences for verbal information and best grasp spoken or written information, while others

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prefer visual information and best grasp information presented as diagrams, pictures or demonstrations. Some students prefer processing information actively, whilst others prefer to think through the information and reflect upon it. These preferences form part of students' unique learning styles. But what exactly are learning styles?

There are various definitions of learning styles found in the literature. For instance, Dunn and Dunn (1993: 2) refer to learning style as 'the way in which each learner begins to concentrate on, process and retain new and difficult information'. Felder (1993: 18) defines students' learning styles as 'characteristic strengths and preferences in the ways they take in information'. However, we found the definition by Keefe (1985) to be the most comprehensive and appropriate for this discussion that is situated in a distance education context. Keefe's definition recognises three domains of style: the cognitive, the affective and the physiological. He justifies and explains these domains as:

- Cognitive elements are internal to information-processing habits.
- Affective elements are motivational processes and are preferential in nature. They are viewed as the typical modes arousing behaviour and respond to matching strategies.
- Physiological elements are rooted in learner reactions to the environment and are responsive to instructional matching. (Keefe, 1985: 138)

Keefe (1985: 140) therefore defines learning style as:

The composite of characteristic cognitive, affective and physiological behaviours that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment.

From the above definition, it is evident that learning styles are an individual's characteristics, consistent approaches and preferences to receiving, perceiving and processing information in a learning situation. The main points to draw from the definition are that learning styles reflect an individual's preferences and choices in a learning situation.

In this chapter we will advocate considering and incorporating learning styles needs in calculus instructional materials for distance education

learners. The underlying assumption is that in a distance education environment a mismatch between learners' preferred learning styles and the way the learning materials are presented does not enhance student learning; and that some of the learning difficulties that students experience emanate from these mismatches, thus contributing to a high failure rate. Addressing learning style needs in learning materials gives one an opportunity to address student learning difficulties as well as stimulating student learning.

The context of the calculus course, specifically the calculus concepts of limit and derivative of a function as offered at the ZOU, is used for the discourse in the chapter.

In general, the limit and derivative of function concepts are important and essential concepts in the study of mathematics and its related disciplines. The limit of a function concept plays a pivotal role in mathematical analysis. Other calculus concepts – such as a differential calculus, integral calculus and approximation theory – use the limit of function as a core concept. Ironically, research on student learning of calculus has indicated that students have difficulties in grasping the key concepts. ZOU undergraduate mathematics students also encounter difficulties with the learning of calculus, as is reflected by the low pass rates in the calculus course at first-year level.

This chapter therefore addresses how learning styles knowledge can be useful to distance educators, both at the ZOU and beyond, in attempts to promote students' learning of calculus. The chapter draws, to a large extent, on the Felder–Silverman learning-styles model, which we will also briefly outline. We will also propose alternative approaches that can be used to profile students' learning styles in a calculus course and elaborate with examples drawn from a small-scale study carried at the ZOU.

### **Why consider learning styles in distance education?**

Keegan (1990), in defining distance education, highlighted some characteristics that are essential for any comprehensive definition of distance education. According to him (1990), definitive characteristics of distance education include the 'quasi-permanent' separation between the teacher and the learner throughout the learning process, the 'quasi-permanent' separation amongst the learners themselves, the influence of an educational institution regarding planning and preparation of learning materials, and the media used to carry the content matter of the course.

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Learning in a distance education environment therefore takes place when the teacher and the learners are wholly or partially separated in terms of time, location or both (Rowntree, 1992).

The characteristics of distance education that Keegan (1990) points out also highlight the geographical dispersion of the distance learners and as a consequence, implicitly implying the individualisation of student learning and the importance of careful pre-planning and preparation of the learning materials. Lockwood (1998) also emphasises self-instructional materials, which are supposed to provide, among other features, expert and standardised content, individual learning and active learning. Distance education learning materials must therefore facilitate the learners' accessing the subject matter by being self-explanatory, self-guiding and meeting the needs of the learners.

The fact that distance teaching is conducted mainly through the use of institutionally pre-prepared learning material packages and systems brings out the beauty and complexity of distance education. It's a 'beauty' on one hand because by the time the students join the institution, everything is all set and ready for their learning. The learning materials, the learning activities, the assessments, the course delivery strategies should be planned and prepared well before the student joins the institution. On the other hand, the complexity lies firstly in that once a course is in presentation there is very little opportunity to modify and adapt the course material (Mercer and Pettit, 2001) to meet the individual learner's needs. Secondly, it is a common phenomenon that distance educators prepare learning materials from which they may never personally have the opportunity to use directly with students – someone else may tutor and evaluate students using the materials, a position that may call for rigorous and thorough consideration of what to include in the learning materials and how to take care of learner diversity in terms of the learning styles.

It is therefore evident that sufficiency for 'self-instruction', as advocated for by Lockwood (1998), should be taken care of during preparation of the learning materials. Pedagogical materials for distance learning are frequently designed without consideration of the individual learner's needs. Materials are presented to learners as if the learners were 'a uniform mass' and as if they learn the same content in the same way. This, however, is not the case, as people are different and do learn and understand the same materials differently. For instance, as noted by Felder (1993), a student who has strong preferences for visual information may find text-based

materials harder to deal with than a student with strong verbal skills.

### **How to find an individual learning styles profile**

One way of profiling a person's learning pattern is on the basis of a learning styles model. Felder and Silverman portray a learning styles model as a model 'that classifies students according to where they fit on a number of scales pertaining to the way they prefer to receive, perceive and process information' (Felder and Silverman, 1988: 674). The categories in the learning styles model can help the distance educator better understand learner characteristics and learner differences, and that knowledge can in turn be used to address mathematics learners' needs. As pointed out by Felder and Spurlin (2005), the instructor can formulate a teaching approach that addresses the needs of all types of learners on the basis of a learning styles model.

### **The Felder–Silverman learning styles model**

A glance at the literature on learning style models yields vast quantities of information and various models. Among others is the Felder–Silverman learning styles model, developed by Richard Felder and Linda Silverman (1988). The original Felder–Silverman learning styles model incorporates dichotomous though continuous dimensions that capture students' preferences with regards to *perceiving information* (sensing or intuitive), *receiving (input) information* (visual or verbal), *organising information* (inductive or deductive), *processing information* (actively or reflectively) and *understanding information* (sequentially or globally). The discussion in this chapter is, however, based on the updated Felder–Silverman model (Felder, 2002). Here the organising dimension has been dropped because of the contradiction that may exist between inductive and deductive presentations at tertiary level, thus leaving a model with only four dimensions.

Although the Felder–Silverman model was designed with dimensions that are particularly relevant to engineering and science education (Felder and Silverman, 1988), the model applies to mathematical-related subjects, since mathematics is in a way academically similar and related to engineering and science. In addition, the categories of the Felder–Silverman model appeal to the mathematics distance educator as the model classifies learners according to how they prefer to perceive, receive, process and understand information. Indeed, the four dimensions of the

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model – perception, input (receiving), processing and understanding – have strong implications for how mathematics subject matter should be presented in distance education learning materials.

According to Felder and Silverman (1988; Felder, 1993) a student's learning style may be defined, in part, in terms of answers to the following questions:

- *Perception dimension*: What type of information does the student preferentially perceive: sensory (sights, sounds, physical sensations) or intuitive (ideas, insights, memories)?
- *Input or receiving dimension*: Through which mode does the student most effectively receive external information: visual or verbal?
- *Processing dimension*: How does the student prefer to process information: actively or reflectively?
- *Understanding dimension*: How does the student progress toward understanding; sequentially or globally?

Though the learning style dimensions of this model are dichotomous, Felder and Silverman (1988) emphasise that the dimensions are to be interpreted as continuous, and not exclusively either/or, and that a student's preference on a given scale may be strong, moderate or nonexistent. The situation can be elaborated diagrammatically, as is shown in Figure 1.

**Figure 1: The Felder–Silverman learning styles dimensions**

Sensory_____	Perception_____	Intuitive_____
Visual_____	Input/Receiving_____	Verbal_____
Active_____	Processing_____	Reflective_____
Sequential_____	Understanding_____	Global_____

### Summary of characteristics of the Felder-Silverman learning style dimensions

Table 1 is a summary of some of the characteristic preference attributes of the Felder–Silverman learning style classification scheme, as summarised from some of their studies (Felder, 1993, 2002; Felder and Henriques, 1995; Felder and Silverman, 1988).

**Table 1: Summary of Felder–Silverman learning style over preference characteristics**

<b>Dimension</b>	<b>Characteristic attributes</b>	<b>Characteristic attributes</b>
<b>Perception</b> <i>Sensing and intuition</i>	Sensing learners tend to: <ul style="list-style-type: none"> <li>• Be concrete thinkers</li> <li>• Prefer connections to real world</li> <li>• Be practically-oriented</li> <li>• Be fact-oriented</li> <li>• Be methodical</li> <li>• Like procedures</li> <li>• Like memorising</li> <li>• Like details</li> <li>• Patient with repetitions</li> <li>• Be comfortable with numerical examples</li> <li>• Be careful and may be slow</li> </ul>	Intuitive learners tend to: <ul style="list-style-type: none"> <li>• Be conceptual</li> <li>• Be innovative</li> <li>• Be theory-oriented</li> <li>• Like abstractions</li> <li>• Deal better with principles and theories</li> <li>• Be comfortable with symbols</li> <li>• Be impatient with details</li> <li>• Be impatient with repetition</li> <li>• Be quick and may be careless</li> </ul>
<b>Input</b> <i>Visual and verbal</i>	Visual learners get more information from what they see and they prefer visual representations, such as: <ul style="list-style-type: none"> <li>• Pictures</li> <li>• Diagrams</li> <li>• Graphs</li> <li>• Flowcharts</li> <li>• Films</li> </ul>	Verbal learners tend to prefer: <ul style="list-style-type: none"> <li>• Written explanations</li> <li>• Spoken, verbal or oral explanations</li> <li>• Context and word problems</li> <li>• Discussion</li> </ul>
<b>Processing</b> <i>Active and reflective</i>	Active learners tend to: <ul style="list-style-type: none"> <li>• Try things out</li> <li>• Like group discussion</li> <li>• Like working with others (group work)</li> <li>• Dislike lectures</li> </ul>	Reflective learners tend to prefer: <ul style="list-style-type: none"> <li>• Thinking things through</li> <li>• Introspection</li> <li>• Working alone</li> </ul>
<b>Understanding</b> <i>Sequential and global</i>	Sequential learners tend to: <ul style="list-style-type: none"> <li>• Prefer material presented in small connected chunks</li> <li>• Learn in linear steps</li> <li>• Be orderly</li> <li>• Like logically connected material</li> <li>• Learn in small incremental steps</li> </ul>	Global learners tend to: <ul style="list-style-type: none"> <li>• Be holistic</li> <li>• Need the big picture</li> <li>• Be systems thinkers</li> <li>• Learn in large leaps</li> <li>• Link/relate new material to prior knowledge/experience</li> </ul>

Felder and Silverman (1988: 676) emphasise that these characteristics are ‘tendencies of learners in the dimensions and must not be taken as

invariable behaviour patterns as everyone has the potential to use both faculties in a dimension'. However, in most cases people tend to favour one over the other; thus illuminating the fact that the dimensions are continua, and that the preferences can be placed on a scale of strong, moderate or nonexistent.

### **Implications for mathematics distance education materials**

Felder and Silverman advocate a balance between the extremes in each of the learning style dimensions. In mathematics, a balance in learning styles can be achieved by using a variety of representations when explaining concepts.

For instance, when preparing and presenting learning materials for a concept in calculus, you need to balance the abstract concepts, such as theories and principles, with concrete information such as facts, tabulated data from experiments or real-life situations, and thus take care of the perception dimension. Intuitive learners can be catered for by the formal mathematical theories, symbols and equations. The sensing learners can be catered for by numerical and tabulated information. In order to take care of the input/receiving dimension, there is a need to balance the visual and the verbal information. Materials can, for instance, be presented with diagrams, graphs or sketches accompanying the symbolic and textual information, so as to reach both visual and verbal learners. To take care of the varied needs in the processing dimension, materials can be presented in ways that will engage both the active and reflective learners, provide work with exercises and activities for balanced practising of skills and include questions that probe individual student reflection. Similarly, the understanding dimension can be taken care of, for instance, by complementing a traditional sequential presentation of concepts with the inclusion of overviews, relating the information being presented to other concepts or courses, as well as providing activities that call for students' creativity.

To accommodate different learning style preferences, many research-based mathematics curricula use a variety of representations to present information. A function can be represented in its graphical, verbal (contextual), symbolic (algebraic) and numerical forms. In the same way, other calculus concepts can be presented using a variety of modes of representation. Movement and motion, for example, can be described with words, pictures or graphs, equations, or in tabular form. The limit of

a function concept can also be explained using the graph of the function, the algebraic equation, the tabulated function values, or the verbal explanations. Furthermore, some mathematical principles and laws, such as laws of limits, can be stated both verbally and symbolically. For example, the 'Sum law' of limits can be presented in the symbolic form as

$$\lim_{x \rightarrow a} [f(x) + g(x)] = \lim_{x \rightarrow a} f(x) + \lim_{x \rightarrow a} g(x),$$

or in a verbal form as the *limit of a sum of functions is the sum of the limits* (Stewart, 1991, 1994). We believe that balanced instruction, where a variety of representation is used, enhances the student's conceptual development and mathematical reasoning. The student then attempts to establish links between the representations, as they attempt to evaluate the soundness of the solutions presented in different forms obtained from the same problem. Research has shown that using a variety of representations enhances relational understanding of concepts. Greeno and Hall (1997) maintain that forms of representation are useful as they aid in constructing understanding and communicating information. Stewart (1994) emphasises 'the rule of four' as a way of facilitating learning.

In attempting to balance between the extremes, there are chances that students may encounter both matching and mismatching of information with their learning styles. We therefore cannot afford not to discuss the two sides of balanced instruction: matching and mismatching of learning styles.

### **Benefits of matching/mismatching instruction to the learning styles**

Research studies have shown that matching instruction with learning styles enhances learning. Claxton and Murrell (1987) note that if individuals have their own habitual ways of representing and structuring information for learning, facilitating instruction consistent with the styles contributes to more effective learning. Claxton and Murrell also posit that matching of students' learning styles is appropriate in working with new tertiary-level students as well as with poorly prepared students. Such an approach will allow students to access information in a format that matches their learning style, consequently eliminating the student's need to 'reorganise' given information. According to Pillay (1998), matching instruction to preferred ways of perceiving and processing information frees up 'cognitive resources' that can be directed to learning. At this point, it is important to

observe that exclusive matching of teaching to learning style does not solve all learning conflicts, as there are other factors such as learner's previous background, and motivation that can influence the amount and quality of learning. However, we share the opinion with Montgomery and Grout (2002) and other learning styles advocates that being self-reflective and explicit about the role of learning styles can enhance student learning.

As we discuss matching information to learning styles, it is essential that we also look at the other side of the coin: mismatching. If instruction is too biased towards one category of a learning styles model, there is a risk of discomfort for the mismatched students. However, the learning styles advocates Claxton and Murrell (1987), Friedman and Alley (1984) and Felder and Brent (2005) argue that although mismatching can be threatening to learning, students must have an opportunity to learn through both their preferred and non-preferred learning styles modes. Mismatching may help the students learn and experience information in new ways, and at times encourage the students to develop critical skills and metacognitive abilities, like insight into own learning. However, purposive mismatching has to be approached carefully as it can cause learning difficulties for students.

### **Importance of profiling students' learning styles in distance education**

As much as we can argue for reaching all learners by taking a balance between extremes in each of the dimensions of the learning styles model into consideration, we can not downplay the importance of profiling student learning styles. Although it is useful for an instructional material designer to know the distribution of the learning styles, the point is not to place each and every learner into one or another of the categories and teach exclusively (Felder, 1993; Felder and Brent, 2005). In any case, it is impossible to instantly attend to each individual student's learning styles needs. This is especially the case in the distance education environment where learning takes place in a situation where learners are separated from their teachers and from each other, and where the materials are pre-prepared.

The information on individual learning style can, however, still be useful to both the distance educator and to the student. On the one hand, learning styles profiles can assist by supporting and motivating instructional decisions (Felder and Brent, 2005; Felder and Spurlin, 2005), thus providing the distance educator with additional information that

can be useful in making the environment more efficient and successful in terms of facilitating learning. On the other hand, learning styles identification can instantly provide useful information for the students. The students can become aware of their learning style preferences and be able to understand what works best for them at different stages and with different issues, or alternatively develop skills of managing and acquiring information presented in the less preferred ways.

### **Instruments for profiling learning styles**

The aspect of the instruments used to identify students' learning styles is essential and cannot be ignored in a discussion about the learning styles in distance education. The fact that from an educator's point of view instructional decisions can be made on the basis of these profiles, and that from a student's point of view learning decisions can be taken on the basis of these learning style profiles implies that it is important to profile the learning styles using instruments that yield accurate information. As such, the appropriate question to address right now is how best can someone profile students' learning styles and what kind of instruments can be used?

### **Learning styles inventories/indexes**

Common types of instruments available for identifying learning styles are the inventories or indexes of learning styles such as the Felder–Solomon Index of Learning Styles (2001), the Kolb's Learning Styles Inventory, and others. Many of these learning styles inventories are in the form of self-report surveys whose item construction and development are based on some theoretical model of learning styles. For instance, the Felder–Solomon Index of Learning Styles (2001) is based on the Felder–Silverman learning styles model (Felder and Silverman, 1988), and the Kolb's Learning Styles Inventory is based on the Kolb's learning style cycle, (Kolb, 1984). As is the case with self-report scales, students rate themselves according to the provided scales. We do, however, have reservations about making decisions about instructional materials based only on the learning style inventories or indexes, as the instrument might not provide sufficient information. The inventories could be exclusive, as they focus on certain variables at the expense of other possibilities (Gregorc, 1979) and might have limited and biased responses. Also, some students may, as noted by Gregorc (1979),

wittingly or unwittingly have a tendency to lie on any self-reporting instrument, and hence distort the true reflection of the student's profile.

### **Other approaches of profiling of learning styles of calculus students**

In order to gain more meaningful and accurate information on learning style profiles, we believe that further phenomenological interrogation is required and this can come from the learners' experiences; including their writings, recordings and verbal accounts of their learning experiences. For example, information can be solicited from interviews or from students' reflective learning journals. Gregorc (1979) and Hill (1979), cited in Henson and Borthwick (1984: 5), recommend the use of interviews and conversations in diagnosing students' learning styles. In an environment like distance education where it is difficult to observe individual students in learning situations, reflective learning journals can be used. Langer (2002) advocates the use of structured learning journals, as they allow the researcher an opportunity to receive information in a specific format, and, at the same time, allow one to compare students' responses and reflections and obtain feedback on specific discussions and learning activities. Analysing and interrogating students' written descriptions of the activities they engage in to overcome difficulties can assist by illuminating some the students' learning styles. Although this can be a long and tedious approach of profiling learning styles, we believe that this approach can give a better manifestation of the actual learning styles, as opposed to only using the inventories/indexes. We also note that the approach can be helpful in an endeavour to develop, adjust or improve instructional materials, as the approach provides an indication of how best to assist students to learn concepts, related by the students themselves. Examples of profiling learning styles using learning journals are given later in the chapter.

### **Learning styles in calculus course at the ZOU**

In this section we provide an example of a text analysis for learning styles incorporation. We will also provide some examples of profiling learning styles from students' learning journals as experienced at the ZOU.

#### **Example: Analysis of text**

This section aims to show how learning styles can be incorporated in a calculus text. We base the discussion on an extract of a text from a ZOU calculus module that deals with the introduction of the limits of functions.

The discussion is specifically oriented towards how to apply learning style principles on a calculus course text. To elaborate this aspect, we are going to look at the extract text in its current status (as it is in the module) in accordance with the Felder–Silverman learning styles model, and propose how to take care of aspects of the Felder–Silverman model that seem not to be optimally addressed in the text.

Figure 2: Extract from the ZOU MTD101 Calculus 1 course module\*

### 3.3 Limits

#### 3.3.1 Intuitive Ideas

Let us start by looking closely at the function

$$f(x) = \frac{x^2 - 9}{x - 3}.$$

We notice that the domain of the function is the set of all real except the real numbers +3. Although  $f$  is not defined at  $x = 3$ , we can calculate the value of  $f$  near 3. The table below shows the values of  $f$  near 3.

$x$	2,9	2,998	2,9999997	3,0001	3,001	3,1
$f(x)$	5,9	5,998	5,9999997	6,0001	6,001	6,1

From the table, we see that as  $x$  approaches 3 from either the left hand side or the right hand side of 3, the values of  $f$  approach the number 6. That is, when  $x$  is near 3,  $f(x)$  is near 6. We then say that 6 is the **limit** of  $f$  as  $x$  approaches 3.

#### 3.3.2 Definition of a Limit

We see that  $f$  has limit  $l$  as  $x$  approaches  $x_0$ , if the closer  $x$  is to  $x_0$ , the closer  $f(x)$  is to  $l$ . Now closeness of  $x$  to  $x_0$  is given by  $|x - x_0|$  and that of  $f(x)$  to  $l$  is given by  $|f(x) - l|$ . The smaller the values of  $|x - x_0|$  and  $|f(x) - l|$  are the closer  $x$  is to  $x_0$  and  $f(x)$  is to  $l$  respectively. Note that we use **absolute differences**  $|x - x_0|$  and  $|f(x) - l|$  since we are considering approaches from **both** the left hand side and the right hand side of  $x_0$  and from above and below  $l$  respectively. Thus  $f$  has limit  $l$  if  $|f(x) - l|$  tends to zero as  $|x - x_0|$  tends to zero i.e.  $|f(x) - l| \rightarrow 0$  as  $|x - x_0| \rightarrow 0$ . Let us now put this more precisely

**Definition 3.1** A function  $f$  which is defined and single-valued for all values of  $x$  near  $x = x_0$  (with the possible exception of  $x = x_0$  itself) has limit  $l$  as  $x$  approaches  $x_0$  if given any  $\varepsilon > 0$  (however small), we can find a positive number  $\delta > 0$  such that whenever  $|x - x_0| < \delta$ ,

$$|f(x) - l| < \varepsilon.$$

\* From Vuma and Mudehwe (2000)

Analysis of the extract:

- The text in the section under consideration in the extract deals with 'limits of functions' and titled 'Limits'. After the heading under section 3.3, the text takes us straight to sub-section 3.3.1. We thus observe the absence of an overview as an introduction to the section. In the framework of the Felder–Silverman model, availing an overview would attend to the needs of the global learners. At the same time, including a sequential presentation of what is covered in the section in the overview would be beneficial to the sequential learners. The overview could also provide the connection between the concepts under discussion in this section with the other concepts in the previous sections of the module or other courses, and therefore cater for those learners (mainly global learners) who prefer to relate what they are learning to previously encountered information.
- Sub-section 3.3.1 serves the purpose of introducing the concept of 'limit of a function  $f(x)$ ' to the learner. We observe that the function  $f(x)$  has been presented in both its algebraic form and tabular form. The tabular form is used to develop the concept of limit of the function  $f(x)$  as  $x$  approaches 3. We also note that written verbal explanations are used to reinforce and state the mathematical task under consideration in plain words, which is 'limit of a function'. In the framework of the Felder–Silverman model, the inclusion of tabulated data to enlighten the behaviour of the function  $f(x)$  near the point 3 would be appealing to sensing learners who have a preference for factual and tabulated data, whilst intuitive learners can derive more benefit from the symbolic expression of  $f(x)$ .

However, what we miss from the text is the geometrical representation (graph) of the function  $f(x)$  which would have been useful in showing the behaviour of the function nearer the point 3 and in showing how the concept can be developed from a graphical perspective. At the same time, including the graph of the function and providing verbal explanations to elucidate the concept under discussion would provide an opportunity for the text to address the needs of both the verbal and the visual aspects of the input/receiving dimensions of the model.

Analysing sub-section 3.3.1 further, we miss the inclusion of other examples elaborating how this viewpoint of limit of function can

be translated to various other functions. This could benefit all the dimensions of the limit of function as the students think, reflect and practise in an attempt to understand and solve the examples. Wrapping up the introductory section of 3.3.1 with a few exercises and activities could be beneficial for independent and self-assessment purposes, and therefore cater for almost all the dimensions of the model. The needs of both the active and reflective learners could be addressed depending on the nature of the exercises and activities.

- The purpose of sub-section 3.3.2 is to express and put across what has been discussed in 3.3.1 in mathematical and symbolic language. The beginning of section 3.3.2 is very abstract compared to section 3.3.1, a move that can be beneficial to the needs of the intuitive learners while at the same time drawing the sensing learners into an appreciation of the symbolic language. However, the introductory part of 3.3.2 could be elaborated further by use of graphical illustrations, showing the position of all the symbols involved  $f(x)$ ,  $l$ ,  $x$ ,  $x_0$ ,  $\varepsilon$  and  $\delta$  relative to each other, whilst at the same time capturing the needs of the visual learners. The current format of presentation is very abstract.

In their reflective learning journal entries recorded when they were studying the limit concept, some students at the ZOU highlighted that the formal  $\varepsilon - \delta$  definition was not meaningful to them at all. For example, one student said, ‘... symbols such as  $\varepsilon$  and  $\delta$  in the definition are there and you do not know what they are for and where they are coming from’. This is an indication that the text does not address some aspects of learning styles. The way the concepts are presented in the course module causes learning conflicts for some students instead of enhancing learning. In this case, it is evident that the concepts are presented in an abstract manner only, a presentation that in the Felder–Silverman framework might present no challenges for the intuitive learners, but could present challenges to sensing, visual and verbal learners.

### **Identifying learning styles from learning journal entries**

In this section, we present two cases of ZOU mathematics distance education students’ learning style profiles that emerged from the students’ entries in their calculus learning journals. This investigation was part of a small scale-study carried out at the ZOU. The cases presented here

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therefore partly give profiles of the students' learning styles that only emerged from the learning journal entries. More rich learning style profiles of the students might have been possible had interviews been conducted, which unfortunately was not possible for the small-scale study. The aim of the following section, however, is to elaborate that it is possible to profile students' learning styles from analysing students' written entries in structured learning journals.

In order for us to follow the learning style identification process from a learning journal, we need briefly to discuss the format of the learning journal used.

### **The learning journal**

The learning journal is a structured diary comprising a learner's self-report and reflections of his/her learning processes as s/he goes through a particular selected section of the course. The guidelines were developed to capture some dimensions of the students' learning styles, as experienced and reported by the students themselves. At the beginning of the semester, students were asked to fill in four structured learning journals, labeled L1, L2, D1 and D2. Journals L1 and L2 were used to make journal entries for the limit of function concepts, and journals D1 and D2 were used similarly for the derivative of function concepts. The journals L1, L2, D1 and D2 were similar in structure, with the only difference being in the content to be referred to in each of them. The split in content was done corresponding to the sections in the module, and was done so as to prevent students from having congested responses when making the journal entries.

The learning journal comprised seven items. Items 1 to 6, which are open questions, mainly seek an insight into the learning style aspects based on the concepts under study.

- Item 1: What do you think are the most important things you have learnt?
- Item 2: Describe new things that you have learnt.

Responses to items 1 and 2 serve to highlight what the student has learnt, and also to capture in the framework of the Felder–Silverman model aspects of the perception dimension, input/receiving dimension and understanding dimension.

- Item 3: Give an example of mathematical task that you are now able to solve.

Responses capture the perception dimension, input/receiving dimension and understanding dimensions.

- Item 4: What did you find difficult in the section(s)?

Responses capture the perception and input/receiving dimension and understanding dimension.

- Item 5: Why did you find this difficult?

Responses capture the perception, the input/receiving as well the understanding dimensions.

- Item 6: How did you try to overcome the difficulties?

Responses to this item would help to capture mainly aspects of the processing dimension. However, aspects pointing to the other dimensions could also be revealed depending on the student's response.

- Item 7: What do you think helped you most to learn the main concepts?

In order to obtain responses to the Item 7 question, guided responses were provided for the student to choose from. The student was asked to choose five out of a choice of 16 responses indicating his/her best answer. The item intended to capture aspects from all four learning style categories. Overall, the most dominant preferences emerging from the responses to Item 7 would contribute to the learning style profile.

### ***Case 1: The case of Janet***

We are now going to present the case of Janet's learning style profile, as it emerged from her learning journals. (Note that pseudonyms have been used for students' names.)

Journal L1:

In response to items 1 and 2, Janet indicated that the most important thing that she had learnt in the section was 'definition of a limit and the finding of a limit from first principles'. However, to the question 'what did you find most difficult?', Janet indicated 'proofs of limits by definition', and the reason for the difficulty was: 'It's abstraction. It requires great mastery of the language involved in order to come up with statements that lead to making sound proofs.' It is evident Janet is not comfortable with abstract materials, and she is also uncomfortable with the mathematical language used, thus giving us a pointer to the sensing dimension. On how she overcame these difficulties, Janet indicated that 're-reading the text and referring to simpler texts' helped her, thus giving indicators for

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*sensing, active processing* and *sequential* dimensions.

Janet indicated that use of 'the left- and right-hand limits and their use in determining whether or not a limit of a function exists' was the new thing that she had learnt. An example of a mathematical task that Janet could now do but could not do before, was the example of a piecewise-defined function for which she wrote that she could now 'sketch  $f(x)$  for  $x \in [-2,4]$ ' and 'use the left- and right-hand limits to find the limit of the function', pointing to *visual presentation*.

Journal L2:

Janet considered that 'theorems on limits' were the most important thing that she had learnt under this section. She indicated that the new things learnt included: 'computing limits of complex functions by first expressing the functions in terms of sums, products, differences and quotients of simple functions, whose limits can be easily evaluated.' This points to the *sequential* and *sensing* dimensions. As in L1, she indicated difficulties with abstract methods: 'the methods of proofs are too abstract'. She attributed this to the language used, which 'required a great deal of appreciation', pointing to the *sensing* and *input* dimensions where it appears Janet is particularly keen on the language (mathematical) used in presentation of the content. Janet said she tried to overcome the difficulties by 'memorising the solution method and then attempting a variety of problems concerning the proofs', pointing to *sensing* and *active processing* dimensions.

Journal D1:

The most important thing that Janet learnt was the 'definition of derivative', the new things learnt was the use of the left- and right-hand derivatives to show differentiability of a function. On what was difficult, Janet highlighted proofs and again attributed this to the mathematical language, another pointer to being a *sensor*. Janet said she overcame the difficulties by: 'Memorising the method of solution and attempting a lot of questions. I also had to look back at related concepts.' This points to *sensing, active* and *sequential* dimensions.

Journal D2:

Janet was very brief in journal D1, only indicating that the most important things she learnt were the rules of differentiation (*sensor*), and emphasising that nothing was difficult for her under this section.

A summary from responses on Item 7 of all the journal entries L1, L2, D1 and D2 indicate the moderate preference for the *global understanding* dimension. However, these were Janet's choices from the responses provided in the section.

Although one cannot make conclusive profiling of Janet's learning styles from just the learning journal, it is evident that some learning-style preferences are manifesting from the descriptions above. There are, for instance, strong pointers to the *sensing* dimension, the *visual dimension* and the *active* dimension. However, the *understanding* dimension is not emerging clearly. Hence, the need for interview arises, and perhaps even some mathematical task analysis. It has also emerged that Janet is 'frustrated' with the way the material is presented in the text. Had the materials been presented taking learning styles into more consideration, some of these frustrations and difficulties, related to language and terminology, might have been avoided.

### **Case 2: The case of Tichaona**

From the learning journal entries we see that Tichaona is a very wordy and detailed person, which gives tendencies of *verbal* and *sensing* dimensions.

Journal L1:

In response to items 1 and 2, Tichaona indicated that the most important thing that he learnt was 'the definition of limit of a function'. However, in response to 'what did you find difficult?', Tichaona indicated that he found application of  $\epsilon$  and  $\delta$  definition of a limit difficult. He wrote: 'The central problem is how to apply these definitions, interpret definitions or even understand the concept of a limit.' As to why this difficulty existed, Tichaona said: 'There is lack of imagination and understanding the language of limits. So what is required is a bit of a lesson delivery or a powerful group discussion.' We see from this that Tichaona is an individual who is in search of deeper understanding, and interpretations of the definitions, which points to tendencies for the *global* and *intuitive* dimensions. He also shows tendencies of *verbal* and *active processing* dimensions. On how he overcame difficulties, Tichaona said: 'I refer to as many books as possible and consult other students.' This points to the *intuitive* and *active processing* dimensions.

Journal L2:

Tichaona indicates that the most important things he learnt, are ‘theorems of limits of function’, and the new thing he learnt was the Sandwich theorem. Tichaona also gave the following ‘problems involving the following limit

$$\lim_{x \rightarrow \infty} \left( 1 + \frac{1}{x} \right)^x = e$$

as the tasks that he can now solve. It is apparent that Tichaona has a preference for symbolic and abstract materials such as theorems and formulae, including the above limit; thus showing tendencies for the intuitive dimension. On what he found difficult, Tichaona said that ‘how to apply the squeeze theorem is the most difficult part’; the reason being that ‘there have been less illustrations in the modules than expected but with time it became easy’ (*visual dimension*). However, in responding to how he overcame the difficulties, Tichaona said: ‘Work through a lot of books, but without illustration or a special lecture, it still is difficult to understand’ (*verbal and visual*). On Journals D1 and D2 Tichaona wrote that he learnt about continuity and differentiability of functions, but he indicated that he found no challenges with these sections. Item 7 responses were dominated by responses pointing to *active*, *verbal* and *visual* tendencies. Similar to Janet, we observe that for Tichaona the following learning-styles preferences emerged: *intuitive*, *balanced verbal*, *visual*, *active* and *global*. Again, in this case, an interview would illuminate the *input* dimension.

### Summary and conclusion

We have noted that because of the nature of distance education where teachers and students are separated and where the learners are separated from one another, distance education presents challenges to educators when it comes to facilitating learning, reaching all the learners and addressing students’ learning styles. Following the Felder–Silverman learning style model, we advocated for a balanced instruction where one attempts to cater for all learning styles needs in the learning materials, and hence facilitate learning that matches with students’ learning style preferences. We argued that in the distance education environment, one way to promote epistemological access could be through the incorporation of learning styles in the learning materials. Text analysis shows that

traditionally this is not done sufficiently. In a calculus course the multiple forms of representation of graphical, verbal/contextual, numerical and algebraic/symbolic forms could be used to address different learning styles. We also discussed the purposes of profiling students' learning styles and how best to profile the learning styles. Analysis of students' entries into their learning journals may be one way of profiling students' learning styles.

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# *Theme: Curriculum, Instruction and Assessment*

In this section, the chapter by Kelly *et al.* presents a brief overview of the literature on the importance of educational assessment, limitations of standard assessments and the assessment approaches used in Swaziland. It argues for the inclusion of performance assessment in the regular assessment practices of students' learning in Swaziland. The reason for the adaptation category is that in order to implement performance assessment in Swaziland, some modifications need to be undertaken first – mainly because of the challenges with large classes and under-resourced science laboratories. An example of the modifications that need to be undertaken is that assessment of practical skills in biology is done through a hands-on practical test or a written alternative to the practical test. The alternative to the practical paper is in fact a 'practical theory paper' which assesses many intellectual skills without any physical manipulation of equipment, except perhaps using a ruler to measure some lengths on a diagram. In Swaziland there is not yet empirical evidence on whether the alternative to the practical test can distinguish students who have had hands-on practical experience in science from those who have not.

The chapter by Ntoi *et al.* describes how a science curriculum with a technology emphasis was developed in Lesotho. It includes a brief outline on the factors which led to the development of such a syllabus. The chapter highlights the process of the Lesotho science technology syllabus development with examples from the syllabus and the textbook written for the syllabus. This chapter argues that incorporating science and technology is a worldwide phenomenon and indeed a curriculum issue. As a result, science curriculum developers need to be familiar with global perspectives when localising ideas related to the incorporation of science and technology, so that they may localise ideas related to the integration of science and technology efficiently in their own context.

Researchers examining the problem of poor performance in science subjects in developing countries in Africa have focused attention on students' culture, teachers, world-views, or on students themselves. The chapter by Dzama *et al.*, however, proposes that learning styles and students' attributions of success or failure in learning

science may also have adverse effects on students' performance in various subjects, including the sciences. In their study, they examine quality of learning and attributions of success or failure among selected students in secondary schools in Malawi against the background of worsening performance in science subjects and a history of poor performance in science that stretches to the early 1940s. The results indicate that although the students were carefully selected, their knowledge of science is still of the positivistic formulation. To most of them, science is 'the study of living and non-living things'. It has little to do with their everyday lives. The students knew no other way of learning science other than reading, listening and working out exercises. Performance of Malawian students in the questionnaire administered suggests that there may be factors related to their learning practices that could be impeding their success in their learning of science. The students consider their teachers to be the most important factor that determines their level of performance. According to students, other factors that determine their level of performance are availability of books and science equipment. Failure of the students to see themselves as an important factor in determining their success in learning may be indicative of a lack of personal initiative in their learning. Absence of student-initiated exercises in students' exercise books seems to support this conclusion. The authors propose that a detailed investigation of the causal links, if any, between students learning styles and attributions, and performance in science be conducted to determine the roles that these variables play among students.

The chapter by Vhurumuku *et al.* debates the various rationales for science education and curriculum reform in Zimbabwe. It is argued that investment in science education, increasing access to science education and science education curriculum change and reform can only contribute to a country's socio-economic development if the political and economic environment is conducive. It is suggested that for sub-Saharan countries, the development of human resources should not only be the major reason for offering secondary-school science, but also be the major determinant of the nature of the curricula. This has implications for curriculum change and reform. The wisdom of 'science education for scientific literacy' is questioned. sub-Saharan countries are advised to be wary of some of the curriculum reform agendas which are more relevant to developed countries than developing countries.

The chapter by Liphoto *et al.* reports on the findings of a research endeavour aimed at exploring the incorporation of indigenous knowledge systems with mainstream school science. The discussion begins by examining the rationale and later the experience of anchoring the incorporation within the context and rationale of the localisation of the science curriculum in Lesotho. It presents a brief outline of instructional material that

encompasses both the scientific world-view and the traditional one. The material was administered as a treatment to two identical groups of pupils. Pupils' perceptions of lightning and thunder were solicited before and after the treatment. This was achieved through questionnaires and interviews. While most pupils did not see a relationship between science and their traditional approach towards lightning, they did have a positive attitude towards being taught both conceptions. The chapter concludes by arguing for a systemic conceptualisation of indigenous knowledge systems and a collaborative approach to the process of incorporating the two systems.

The study reported on in the chapter by Mikalsen *et al.* is part of a large-scale study exploring process skills used by South African and Norwegian Grade 8 to 10 students in performing various cognitive tasks. The central concern in this chapter is to determine South African and Norwegian Grade 8 and 9 students' conceptions of gases. An additional aim has been to identify the process skills they use when solving problems on gases. The need for learners to possess process skills are greatly stressed in both the curriculum and research literature. The study in this chapter specifically tries to reveal the thinking process behind the students' performance on the tasks on gases. The students in both countries had an average score of 38% on all questions in the questionnaire used; but the analysis also showed great variety in the mean score on the individual question. The conclusion seems to be that South Africa and Norway have a situation where the majority of the school population is neither able to answer high-order questions nor display critical process skills. This is a grave situation, not only for the teachers of these subjects, curriculum developers and science educators in Norway and South Africa, but also for stakeholders in other countries where a similar situation exists.

It is well known that socio-economic status impacts upon achievement. Opolot-Okorut *et al.* pursue the differences and similarities between practices in low- and high-achieving secondary schools in Uganda. The subject of interest is school mathematics. The analysis reveals differences and similarities with respect to (1) the instructional resources, (2) teaching arrangement patterns, (3) student diagnosis patterns, and (4) the provision of additional teaching sessions. The findings are consistent with the global trend of there being a correlation between levels of achievement and socio-economic status.

Kwaira *et al.* report on recent developments in Zimbabwe which have culminated in Design and Technology being adopted as a subject at A-Level and as an approach at lower levels of the secondary school system. The advent of this concept has meant

the proliferation of new perspectives regarding instructional practice in technical education. In most cases, educational reforms have been associated with the use of new materials. In Zimbabwe, the nature of reforms has meant the introduction of new syllabi, demanding appropriate instructional materials at various levels. The chapter by Kwaira *et al.* is based on a pilot study which formed part of a major doctoral degree project pursued with the University of the Western Cape in South Africa between 2002 and 2006. The pilot study looked at the design and development of the Material Science course and the effect on the perceptions of teachers regarding instructional practice in Design and Technology. The study found that teachers, through their participation in the process of instructional materials development, contributed towards the design and development of the proposed instructional materials; thereby contributing towards their professional development. This participation helped establish a foundation for the proposed programme for the preparation of initial teacher education and training. Teachers who participated in the proposed in-service programme appeared to be highly motivated and appeared to have experienced personal growth. A sense of ownership was noted among the teachers.

# *8. Performance Assessment in Science: Some Experiences of Teachers and Students in Swaziland*

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## **Abstract**

This chapter presents a brief overview of the literature on the importance of educational assessment, the limitations of standard assessments, and the assessment approaches used in Swaziland to justify the need to include performance assessment in the regular assessment of science students in Swaziland. The construction of the performance tasks and scoring rubrics by following guidelines given in literature is outlined. The experiences of teachers and students using the performance assessments in secondary school science are described in their voices. These experiences highlight the strengths and limitations of performance assessments; particularly for Swaziland where classes are large and resources limited. The experiences of students indicate that students would benefit significantly from performance assessment – not just for assessment purposes, but for improving their understanding of science and developing their thinking skills. This would be possible because students became more attentive during class activities and more serious and committed when working on the tasks. The chapter closes by summarising the experiences while acknowledging the need to combine standard and performance assessments in a complementary way to holistically assess students' knowledge and skills and the need for further research on the use of performance assessment.

## Introduction

The influence of educational assessment on education systems is evident in its effects on curriculum design, education policies, institutions of learning, teachers and their teaching and assessment styles, and learners and their learning and studying styles. It is normal practice that when a new curriculum is introduced an examination prototype is provided to guide both teachers and students on the assessment expectations and the structure of examination papers for the given curriculum. Educational assessment is thus an integral component of the education process, in particular teaching and learning (Aschbacher, 1991; Gipps and Stobart, 2003; Shepard, 2000). According to Broadfoot (1996: 21–22):

... assessment is *the* most powerful policy tool in education ... and will probably continue to be the single most significant influence on the quality and shape of students' educational experience and hence their learning.

It is not the intention of this chapter to discuss assessment in depth, but a brief look at assessment and its purposes is necessary for a discussion of one of the new assessment approaches that has been advocated in the past few years. Educational assessment can be perceived as an endeavour by teachers to ascertain the status of students' knowledge (cognitive understandings and abilities), skills and attitudes as variables of educational interest (Popham, 1999). Educational assessment not only encompasses the techniques teachers and examining bodies apply when grading students' knowledge and skills or comparing them to one another (Wiggins, 1996/1997); it is also a means to help students learn and teachers improve their instruction. Educational assessment should thus be viewed as *assessment for learning and skills development* and not simply as *assessment of learning*. In assessment for learning, the assessment activities are designed to contribute to the acquisition and consolidation of student knowledge and skills. The customary ranking of students in order to certify learning or evaluating programmes should be a secondary use of assessment (Gipps and Stobart, 2003; Shepard, 2000; Wiggins, 1996/1997).

Assessment activities produce information that serves several functions of significance to both the learner and the teacher. Teachers may use such information for summative and/or formative purposes. In summative assessment, such as in the case of end of term or year and national

examinations, the assessment results provide a summary of the students' overall performance. This summary forms the basis for judging how well students' learning attained curriculum goals, and deciding on students' progression to the next class or further studies. The summary is also useful for comparing students with one another (norm-referenced assessment) and for preparing students' reports for parents, administrators and inspectors or other interested agencies (Biehler and Snowman, 1997). Summative assessment data does not always filter back into the classroom to impact on instruction or directly improve learning. Summative assessments do, however, influence instruction indirectly; such as when teachers 'teach to the test' and select those learning activities that they feel are emphasised in examinations and put more time and effort into preparing their students tests and examinations (Gipps and Stobart, 2003; Moorcroft *et al.*, 2000). In the process, students may consolidate and master the content of examination questions rather than the skill of tackling assessment tasks or acquiring a wider range of competencies.

In using assessment information for formative purposes, teachers make judgements about the strengths and weaknesses of individual students in achieving curriculum goals and the effectiveness of instruction to help students achieve instructional objectives. It also helps teachers to decide how to improve instruction and promote productive interactions with their students (Biehler and Snowman, 1997; Elliot *et al.*, 2000). Formative use of assessment information thus provides a link between assessment and classroom instruction by enabling teachers to give clear feedback to their students on their learning. Through the feedback, students become aware of target learning outcomes, the kind of performance they need in order to succeed and where they need to apply effort (Elliot *et al.*, 2000). Students can use this feedback to actively assess learning at a personal level and set goals and academic expectations for themselves. It is indeed the responsibility of students to act on feedback from assessment tasks to improve their understanding and performance (Stepanek, 2002).

Though assessment is important in the education of students, Goldstein and Lewis (1996: ix) observe that it 'is often poorly understood, its purpose confused and its design inadequate', and therefore inefficiently used. Every school curriculum specifies learning goals or outcomes that describe what a student will be able to do with what s/he knows in a given context as a result of a set of learning experiences through that curriculum. But the assessment of student learning from such curricula is rarely as comprehensive as the

specified goal. For a long time educational assessments have utilised what has become known as traditional or standard testing models; namely, standardised and non-standardised tests as instruments of measurement. Standardised tests, which comprise objective-type items such as multiple-choice and closed questions, undergo a rigorous process of validation and reliability testing during preparation (Sanders and Horn, 1995; Popham, 1999). They are also administered, scored and interpreted in a standardised manner (Popham, 1999). Such tests have proved most appropriate for high-stakes assessments to provide summative information that is used to compare students, make generalisations about their achievement and inform policy decisions. Non-standardised tests, on the other hand, are generally prepared and used by teachers in their classrooms and are used in the evaluation of students' learning (Sanders and Horn, 1995). While these standard assessment models (the structured or short answer and objective-based items) may have the required validity and reliability qualities for measurement and testing, they tend to have a narrow focus on the attributes assessed, with an emphasis on recall of knowledge. There seems to be a trade off of validity and reliability for a narrower coverage of goals assessed. Information obtained from traditional assessment models does not adequately reflect the quality of students' thinking and their level of understanding (Nickerson, 1989, in Aschbacher, 1991) The poor attention given to measuring higher-order thinking skills and intellectual and manipulative processes in standard assessments has led to the strong criticism levelled against standard assessment (Sanders and Horn, 1995). In addition, their extensive use for large-scale and national-level assessment has been found to affect classroom instruction and the curriculum. Shepard (2000: 1071) succinctly captures an undesirable and misleading conception that may be developed through the exclusive use of standard assessment formats by noting that:

... once knowledge of the curriculum became encapsulated and presented in this type of items (**multiple choice items**), we can reasonably say that these formats locked in and perpetuated a particular conception of subject matter. [Emphasis added]

From Shepard's statement one can appreciate the unintentional effects of the exclusive use of objective-based items on views held about a subject. For example, such assessments communicate to students that there is one

correct answer to every question, that there is great value in learning by rote memorisation and recall of memorised information in tests (Moorcroft, *et al.*, 2000), and that there is no need to focus on untested sections of the curriculum (Baker *et al.*, 1990, in Aschbacher 1991). 'Teaching to the test' is further encouraged by the reactions displayed by the general public or people with an interest in national examination results. There is usually a general panic among students who took examinations and their teachers and parents when external examinations results are to be released. In Swaziland, if students perform poorly in these external examinations, officials from the Ministry of Education visit the schools to ascertain why students performed poorly. The listing, in the media, of the top ten schools according to the best results and the pride schools show if they maintain their positions in this list or hope of moving up the list is another results fever, in which teachers teach to results and strategise to ensure best results so as to get onto the list. School management boards strategise on ways of further improving school performance. In addition, experience from teaching to the test has been positive with high student achievement in external examinations. Many students succeed in national or external examinations through memorisation and proceed to tertiary institutions, where they may begin to experience some learning difficulties. Teachers are also under pressure to go over as many topics as possible each year and prepare students for achievement in examinations. In the process they lose out on opportunities of exploring the subject fully with their students (Moorcroft *et al.*, 2000). Assessment-directed teaching thus deprives students of real-life experiences of raising questions about observations, constructing responses, identifying problems and finding solutions to those problems.

### **School science assessment in Swaziland**

The education system in Swaziland is three-tiered: seven years' primary level (6–12-year-olds), three years' junior secondary level (13–15-year-olds) and two senior secondary level (high school, 16–17-year-olds). These are estimate ages and exclude class repetitions. Each of these levels ends in an external examination. The primary and junior secondary level follow local curricula and take locally set examinations. All science examinations, including internal examinations and tests, at these levels are taken as theory papers with no practical work. The senior level takes a school-leaving examination, the General Certificate of Education (GCE) Ordinary

Level examinations, offered by the University of Cambridge in the UK.

Swaziland has undergone a process of changing from the GCE examinations to the International General Certificate of Secondary Education (IGCSE) examinations (also from the University of Cambridge). In line with stipulations by the Ministry of Education (2005), GCE examinations were written for the last time in November 2006. The IGCSE programme was introduced in Form 4 (Grade 11) in January 2006 and O-Level examinations were written for the first time by Form 5 students in state schools in 2007.

Swaziland is also undergoing major curriculum reform. Syllabi are being drawn up and teaching materials are being developed for nearly all subjects offered at school level. The use of the IGCSE syllabi and examinations will continue until the local syllabi are ready for implementation at the senior level. The lower levels follow the locally developed syllabi, which are currently undergoing piloting in various subjects. The new science curriculum for primary and junior secondary levels has no indication of utilising assessment through practical work though the senior level science subjects (physical science, biology and combined science) to be offered in Swaziland demand assessment of practical skills.

In Swaziland assessment of learning in science takes place through two main approaches: internal school assessment (formative and summative) and external examinations (summative), taken at the end of each level as mentioned above. Internal school assessment utilises teacher-made monthly tests and end-of-topic tests. Both use questions that are structured in a similar way to external examinations (and in many instances are simply prepared by picking relevant questions from past examinations). Classes that take external examinations are given trial examinations during the second term. These mid-year examinations are usually complete past examinations papers. Form V (Grade 12) students write the GCE June papers for their mock examinations. At the lower levels, these examinations papers are designed by the teachers in the schools or a teacher appointed by the Swaziland Science Teachers' Association. The mock examinations do not include any practical work, except for biology at the senior level, though questions that are based on practical activities can be included in the written examinations. The assessment of practical skills in biology is done through a hands-on practical test or a written alternative to the practical test. The alternative to the practical paper is in fact a 'practical theory paper' which assesses many intellectual

skills without any physical manipulation of equipment, except perhaps using a ruler to measure length on a diagram. Intellectual skills such as extracting and interpreting data from given diagrams (e.g. thermometer or volume readings), drawing diagrams to scale, drawing and interpreting graphs are assessed. Experience has shown that students achieve better in the hands-on practical test where they manipulate equipment than in the alternative paper. However, the reasons for the observed disparity have not been explored as yet. It is speculated though that the continued use of the alternative paper for assessing students' practical skills in Swaziland is dictated by the poor availability of equipment to set up for individual students in the practical examination. Experiences from the USA show that hands-on performance assessment can distinguish students who have experience in hands-on science from students who do not (Shavelson *et al.*, 1991). Students taught in predominantly traditional approaches will have less, if any, practice with hands-on tasks and therefore be unfairly assessed if practical-based assessments are used on them. The introduction of IGCSE is a challenge for teachers to ensure fair assessment of students' intellectual and practical skills by providing more opportunities for them to practise hands-on and intellectual skills. In Swaziland, there is as yet no empirical evidence as to whether the alternative to the practical test can distinguish students who have had hands-on practical experience in science from those who have not.

### **Call for more inclusive assessments**

With the increase in research findings on assessment practices, it has become evident that there is a need for assessment models that will capture a wider range of assessed attributes than has been the case in the past (Saskatchewan Education, 1993). This is not to say that the new assessment approaches being proposed are to replace those currently used. Many educators in formal settings are exploring the effectiveness of using alternative assessments to appraise the attainment of learning outcomes by students (Gipps and Stobart, 2003; Shepard, 2000). The purpose of assessment is to measure how much students know about a topic or subject and what they are able to do with the knowledge in context. The instrument used in such measurements should therefore provide accurate information about the student's level of knowledge (Roberts and Gott, 2004). It is anticipated that alternative assessments will improve the alignment between curriculum goals, teaching and learning, and assessment.

Alternative assessments comprise the use of alternative assessment tools as well as the use of assessment as a learning process. The tasks used for assessment of learning can also be used as exercises through which students can further explore their understanding and application of knowledge in a topic of study. Since they focus on both assessment of achievement and developing understanding, they help students learn the contents and skills targeted by the assessment tasks (Gipps and Stobart, 2003; Moorcroft *et al.*, 2000). The tasks used in alternative assessment may range in complexity from simple extended multiple choice questions (restricted response format) to an in-depth scientific investigation (extended response format) (Linn and Gronlund, 2000; Moorcroft *et al.*, 2000) as is the case in performance assessment.

In this chapter performance assessment is used to refer to assessment techniques that integrate science investigations, such as hands-on practical tasks to measure and evaluate a student's content and procedural knowledge, and his/her ability to use the knowledge in reasoning and solving problems. Students are able to demonstrate their knowledge, skill and work habits through:

- Manipulating and operating scientific instruments and equipment to generate relevant data.
- Recording, analysing and interpreting data.
- Drawing relevant conclusions from data.
- Communicating the product of their investigation orally and in written reports.

In performing the assessment task the students may apply a procedure learned in class, a combination and integration of procedures, as well as thoughtful adaptation of their knowledge to the given task (Brualdi, 1998; Elliot, 1995; Linn and Gronlund, 2000; Slater, n.d.).

Performance assessments are more complex than objective-type tests in that they measure multiple reasoning and knowledge (declarative and schematic dimensions of knowledge). Constructing good performance assessment tasks requires considerable time. Several trial runs with students to get their input are necessary before the tasks can be used for the actual assessment (Shavelson and Baxter, 1992). These authors further advise that good performance assessment tasks are essential if they are to positively influence teaching. Therefore, educators are cautioned not to assume that changing the assessment formats will necessarily change teaching styles;

and as such the use of performance assessments with teachers who teach to the test will improve their teaching. Teaching to poorly constructed performance tests may lead to distorted hands-on science teaching.

If performance assessments are to influence teaching, then the tasks and corresponding rubrics need to be carefully constructed and scorers adequately trained. Studies on performance assessment have shown that specific scoring criteria and examples showing expected competencies are essential for consistent evaluation through performance assessments. Indicating to students the expected performances regarding the tasks prior to their attempting the task motivates them to improve their performance (Slater, n.d.; Gipps and Stobart, 2003).

### **Performance assessments in Swaziland**

Since the use of practical work-based science assessments for the junior secondary level is non-existent in Swaziland, students only encounter practical-based assessment in biology at the senior level. In an attempt to expose junior science students to performance assessments, an exploratory study by Kelly (2007) involving a group of four teachers and their seven classes of students was conducted. In the study three performance assessments tasks in two topics; electricity and air and living things were administered to each of the seven classes. These assessments were embedded in a contextualised science teaching approach. This approach has been adopted for the new science curriculum being developed in Swaziland. Thereafter, the experiences of the participating teachers and students regarding the implementation of performance-based assessment were obtained through class observations, interviews and questionnaires.

The performance tasks used in the study by Kelly comprised four parts, following a design also used by Solano-Flores *et al.* (1999). The tasks directed students to demonstrate their knowledge and procedural skills through planning, investigating and recording, analysing and interpreting data, and applying the data in a given situation.

When constructing the performance assessment tasks, attempts were made to increase the validity of the tasks and reliability of the scoring rubrics by following guidelines for generating suitable tasks outlined by Linn and Gronlund (2000); Stiggins (1995, in Brualdi, 1998) and Airasian (1991, in Brualdi, 1998). Developing high-quality performance assessment tasks requires careful construction of both the performance task and ways in which the tasks are to be scored. The first step in the construction of

the performance task was to study the syllabus objectives of the Swaziland Integrated Science Programme (SWISP) and the content in each of the topics Electricity and Air and Living Things. SWISP is currently offered at the junior secondary level and is being phased in. In October 2008 the national examination for the new science curriculum was written for the first time. The teaching materials to be used by the teachers and students were also analysed to identify skills and knowledge targeted in them. Learning outcomes were then developed to outline the knowledge and skills (intellectual and manipulative) that learners were to develop through the study of each topic for a contextualised teaching approach, as emphasised in the teaching material.

The next step was to isolate those skills that could not be easily assessed by objective-type questions. This second step was followed by the construction of tasks that focused on selected outcomes and preferred skills. Each task indicated clearly what students were expected to investigate (see Appendix 1). To check that the instructions were clear, each task was tried out by the researcher. While constructing the task, possible scoring criteria were identified and these were further modified when the performance task was tested. The criteria thought to be important were selected and assigned a score. The criteria were then arranged in the order in which they were anticipated to occur. The tasks and scoring rubrics were reviewed by colleagues at the University of Swaziland and the supervisors of the study. After amendments, the tasks were pilot-tested with a group of students who followed SWISP and had already done the topics.

The performance tasks were administered to students in groups after the lessons involving the concepts and skills had been done. This was to ensure that students were familiar with the concepts and had hopefully practised the skills required. The use of group work for practical activities is a common practice in science classrooms in Swaziland, and possibly in many other countries. Groups of students were used because there was insufficient equipment for students to work on their own or in pairs. Group work was also suitable for administering the tasks because the large classes made it difficult to monitor and observe students when working in pairs or individually. For performance assessment tasks, group work had an added advantage. According to Slater (n.d.) performance on the tasks improves if students interact among themselves and with the teacher while engaged in the task. This characteristic of performance assessments shows the importance of human support if availed to the students during

the assessment process. Such support is not permitted in traditional assessment models.

In responding to the tasks, students discussed and 'sketched' out a plan of how they would investigate the problem given in the task and indicated how they would record their results. Plans were to be approved by the teacher before the students could proceed to investigate and collect data and continue with the rest of the task as outlined in the task sheet. Approval of the plans was essential for ensuring that the investigations generated acceptable and usable data from which students could improve their understanding of the concepts dealt with in the task.

Participants expressed mixed feelings about their experiences with the use of performance tasks. Both teachers and students thought that performance assessments had potential for use as regular assessment in science learning in schools in Swaziland, but also posed some challenges for users. Some of the apparent problems, however, could be short lived and overcome over time as students and teachers become more familiar with the assessment approach and its requirements. The experience of teachers and the students are discussed below.

### **Performance tasks and learning**

Whilst both teachers and students felt that the tasks were more challenging and difficult because some of the questions were higher-level for the students, they were optimistic about the continued use of performance assessment tasks. The tasks benefited students' learning in several ways; such as helping them understand science and improving their retention of the subject content. They thought:

It's easier to understand practical than theory because in practicals it is not easy to forget what you did practically. (Group 3, School M3)

The performance tasks engaged students in thinking processes they were not normally exposed to, which they appreciated (even if they found it rather difficult at first). They seemed convinced that once they were used to the way the questions were asked they would be able to handle them. Their appreciation of the thinking opportunities afforded by the tasks is exemplified in the interview with Norah:

Norah: That was ok. But when you come to this one, 'Which of the material you tested would be most suitable for replacing part B labelled in the picture?' Then you had to use your mind, like look at the part B know what it is used for, what its function is, so it was like very difficult for us.

Researcher: So it was very difficult?

Norah: Mmm. You had to think. Yet we usually have questions like what is photosynthesis and you just know that from the notes. Here you had to use your mind plus what you know from class.

Researcher: Mmm. Did that help you?

Norah: Yes it did.

Researcher: Ok. I'm talking about the questions that make you think.

Norah: I think that they help us a lot because we get used to this way of asking. And, err, I think it's a very good way of asking, although it is very difficult because we are still not used to it. (School M4 interview group)

Students recognised that the tasks improved development of other important qualities such as working independently as well as practical and intellectual skills:

It helps us develop tricks of being 100% observant which we may need, e.g. when helping at home.

It gives us experience of following instructions and doing tests which we will need at higher institutions.

It gives the experience of doing things on our own with little or no help from the teacher.

It broadened our minds as we argued to get the right conclusion. (Group 2, School M3)

One could justifiably argue about these views that they are peculiar to practical work and not necessarily relevant to performance assessment tasks. Students could have arrived at these claims from regular practical activities, and the claims by these students could indicate a situation where practical work was not a common feature in their science lessons.

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What most students appreciated, was doing the tasks in groups. Group discussions allowed them to learn from one another and they had better chances of improving their marks from the group effort.

Good because it helps us to understand more easily than when done individually. For example, we need to work as a group so that we can discuss. (Group 6 School M2)

Good to do practical test because if someone don't (sic) know the answer or how to do the practicals we are able to help him to understand. (Group 4, School M2)

Performance assessment tasks encouraged students to be more attentive during class when they were working on practical activities or when the teacher was demonstrating, as the excerpt below illustrates.

Jill: Yes it becomes better because in class you don't concentrate when we are doing experiments. If we do practicals (*performance tasks*) we will know that after this experiment there's gonna be a practical that we will do. So we concentrate on what is going on so it would be easier in the ... (sentence not completed).

Researcher: Ah, so you pay more attention.

Jill: We pay more attention to what the teacher is doing because you know what's going to happen afterwards. (School M4 interview group)

Low concentration levels by students during teaching time may indeed have caused them to miss out on some crucial practical activities, and the use of performance assessment tasks could motivate them to be more attentive during lesson activities. Students who tend to be playful during demonstrations miss out and have great difficulty with the performance tasks. This manifested itself in students clearly not knowing what to do or being unable to select relevant information when doing the performance tasks.

Performance tasks also provided a second chance for students to revisit what had been taught with the help of colleagues. Tasks were thus seen as learning activities. Most of the learning was attributed to both the task itself and the collaboration among group members. The exchange of ideas,

reminders and explanations from group members helped consolidate their understanding of the science ideas in the tasks.

Both students and teachers felt that students' efficiency in responding to the performance tasks improved with time as they engaged in more performance assessment tasks.

Researcher: So are you attributing your doing well to being familiar now with the way of testing?

Norah: We are improving, which means it's a good way of asking. Our minds are being opened and we know that questions can be asked in a different way.

Researcher: So do you think that the practical test helps you improve?

Norah: Yes, our way of thinking, studying, applying things.  
(School M4 interview group)

The performance tasks have the potential to influence students' ways of preparing for tests. Students were becoming aware that there are different questioning styles in science assessments that needed a different style of studying. In the first task they did not know what to expect and their preparation was similar to that used for standard tests – memorising. In the second and third tasks students were more comfortable and confident in tackling the tasks, except that the second task (attached in Appendix 1) required calculations which some students had difficulties with. Improvement in scores may be due to other factors besides familiarity with performance task. The level of difficulty of the tasks used and the abstractness of the concepts dealt with varied. The electricity tasks were found to be more challenging than the task on testing gases. Attempts were made to make the task on gases challenging by not specifying what students would use to carry out the tests on a limited sample of gases, but to ask and be supplied with whatever they needed. Those who were not sure of what to use requested everything that was used in class instead of material for the key tests for oxygen and carbon dioxide.

Doing the performance tasks in groups contributed to the development of certain affective aspects such as cooperation, socialising, listening to and helping other people, and communication skills. Teachers appreciated the quality of verbal interactions students engaged in and the seriousness with which they discussed their views. Students participated in the

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discussion more seriously because they were taking a test. The change in the level of seriousness was observed by the teachers.

Josephine: Ya because they know it's a test they normally take it seriously. If it's just, err, practical work in class it may not be as serious as ... (sentence not completed).

Researcher: What did you notice? Did you notice any difference?

Josephine: Yes there was a difference. They were actually more committed when they were doing the test, because they know that it will go with marks. They are usually more serious if it's a test than when it is an activity in class. (Josephine, interview)

The tasks somehow forced the students to participate in the practical activity:

Lorraine: The use of performance tasks. In no way that one would sit back and not participate in the performance tasks. Maybe because they know that they are being assessed on that I'm not sure but somehow it helps them to take part. (Teachers' focus group discussion)

The use of group work for performance tasks was not always perceived on a positive note. There were several limitations to it. The level of participation was not always encouraging, as some group members did not participate. Whilst there may not have been sufficient opportunities for all to manipulate the equipment, there were other ways in which more students could have participated, such as giving ideas, recording, passing material to one another and collective reading of scales. Another concern was awarding all group members the same mark because it was felt that some did not deserve the marks.

Students recognised that it is beneficial to participate in group discussion. No participating members were doing so to their detriment:

It is neither good nor bad but acknowledgeable (as some contribute and realise the capability, some relax, in short it is good to those who take part or are positive and interested and bad to those who are lazy and negative) (sic). (Group 4, School M2)

Teaching to the test cannot be escaped, even with performance assessments. This was demonstrated during a discussion with Josephine on the use of scoring rubrics for the performance tasks. She was of the view that there was too much detail in the scoring guide that teachers did not emphasise in their teaching. If teachers knew what students would be assessed on, they would pay more attention to those aspects in their teaching.

Researcher: So you think it would be more helpful for the teacher to be aware of the scoring guide whilst they are teaching in order to focus on those skills that would be assessed. (Yes) I mean to emphasise those skills that would be assessed before they are assessed.

Josephine: Ya. I think it would change our teaching, the way we teach the topic. And if you know they will be assessed on the details of how they do things then we would be careful of those details. (Josephine interview)

Josephine was concerned that the rubrics were too detailed and that she had not gone into those details while she was teaching. Seeing that this is the case, a question comes to mind as to whether teachers should be aware of the rubrics in advance, or is it enough to tell students what the assessment criteria are at the point of administering the performance task? Would an emphasis on certain skills during teaching be so harmful to the education of students, seeing that skills and procedures have wider applicability, though some may be content dependent? There is, however, a caution to be observed here regarding the communication of scoring criteria. Disclosing detail of the assessed procedures and whether those procedures are of high significance could serve to discriminate between careful students and those who are careless during the assessment.

### **Interactive learning**

Performance assessment tasks allow interactions between students and teachers where students can raise questions with teachers and teachers can redirect students in their work. Students engage in further learning as they interact with the teachers during the performance of the tasks. Inna's reassurance regarding the use of performance assessment tasks was:

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... that we are there to help them, it's not just that we leave them on their own until they are confused. We help them ... we are there for them. Sometimes I go around and subtract marks from them and tell them their mistakes like 'can't you see you are using a scale from 0-15 instead of ...' and the students tend to see their mistakes, then they realise their mistake. (Inna interview)

Teachers used different approaches to support and guide students while performing the assessment tasks, particularly at the planning stage. Students also had to check with the teacher if their plans were acceptable. The approval of plans was necessary to ensure that students produced appropriate plans and obtained interpretable and useable data for the other sections of the task. In one approach the teachers referred students to the instructions and encouraged them to compare their plan with the instruction to see if they had addressed the requirements of the task. In this way students could evaluate their own work against some criteria – the instruction, in this case. In another approach, the teachers used questions to guide and direct students to correct any error or omission in their plans.

These interactions were particularly helpful for students who had a poor understanding of the language of instruction, and therefore had difficulty understanding the tasks and its requirements. For some students, interpreting the tasks was a problem, but once the teacher had assisted them they were able to get on with the task with ease.

Inna: Ya, the tendency is that they would call us as teachers. Sometimes personally I would observe that maybe they are not approaching whatever they are supposed to correctly. Then I would pose the question which somehow is going to help them. Then they would say: 'Oh okay!' Then they would do the correct thing. But as far as awarding marks, it wasn't a problem because I would just subtract a mark if now there is something that you know. (Teachers' focus group discussion)

Students appreciated doing the performance tasks in groups and the assistance teachers provided, both of which improved their marks. Some groups consulted the teacher for almost every step of the performance

task, as if they could not move a step without approval from the teacher. The teacher felt the students had a problem with confidence. There is, however, a strong focus on scoring marks, so the calling of the teacher could have been an attempt to obtain as many marks as possible. Teachers needed to be cautious so as not to give too much guidance and give away the responses to the task. The students were unhappy when the teachers left them to think more about their ideas without giving them a direct response. The deduction of marks for consultations that were designed to correct errors was not appreciated.

### **Duration of tasks**

Students felt that the tasks took a long time to complete. Teachers did not feel that the time students spent working on the task was excessive, especially when conducted with groups of students. The time issue associated with implementing performance assessment tasks can be viewed from a different perspective. The development of the tasks and scoring rubrics takes time for the developer, and teachers would find it quite difficult to produce such tasks considering the rigour of their construction and, to some extent, their teaching loads (though this should not deter them from making use of performance tasks in their classes). Organising and setting up the material required for performing the first task requires additional assistance, possibly from a colleague teacher or a technician. Students took a long time on the first task because they were still not familiar with the tasks. Some of the reasons for the delays given by the interviewees are as follows:

- Inna: Some groups take a long time to initiate their work, they sit you know and read as if now they are meeting something they have never met before. They kind of, you know, what can I say; they drag in such a way that most of time is now wasted, they don't jump into their work and do it quickly. ... They just drag in such a way that one can think that they don't finish because you know that maybe the time was limited or what. The problem lies with them I can say.
- Lorraine: They are not confident.
- Inna: Ya. They are not confident

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Lorraine: At times they wait for the others to get started so that they can check (I agrees with L). (Teachers' focus group discussion)

Both teachers and students were concerned that discussions in the groups took a lot of time before they agreed on how to plan and respond to a task and they could therefore not complete the task within the allocated time, and therefore not get all the marks they would get if they finished the task. A student from M4 expressed her concerns thus:

The second one [performance task attached in Appendix 1] was hard as you were needed to work not just work but working hard. But as a group we came with different ideas, you didn't know what was the correct one for you. We were told to make a plan, we even didn't know which plan to show to the teacher and before we do it and you find that we took a lot of time because we could do this one and find out that, no its wrong and we had to start afresh that's why we took a lot of time. (Group 3 School M4 interview)

Calling and waiting for the teacher to check and approve plans also contributed to the delays. For some, the frequency of teacher visits was very high, making it difficult for the teacher to adequately attend to all the groups.

Whilst there were concerns of time taken during group discussion for performance assessment, teachers and a number of the students appreciated the exchange of ideas and the help they rendered one another in explaining concepts and procedures to one another. Another concern was that not all students in the group participated and/or contributed to the discussions, yet they benefited from group scores; and sometimes correct ideas were ignored, depending on how convincing the source was in expressing the idea. Teachers were concerned that while students may get higher marks than they deserved through group work tasks, top achieving students could be disadvantaged in a group with under-achieving students.

Administering performance assessment tasks in groups could be modified to allow students to work together on the planning and investigating stages of the task and thereafter work on the analysis, interpretation and application of the data individually, but teachers felt that this would increase their workload and the time taken to score and return students' reports and feedback.

## **Resources**

Teachers acknowledged the limited applicability of performance assessments for school science because of the very large class sizes in many secondary schools in Swaziland (in the study there were between 35 and 52 students per class). The shortage of science teachers worsens the situation by increasing teaching loads.

The situation with large classes and high teaching loads may inhibit a teacher's desire to construct and/or administer performance assessment tasks. Administering performance tasks to groups of students allowed teachers time to interact with more students, reduced the time spent on scoring the reports and enabled rapid turnaround of scripts and feedback to students. Students also received feedback while doing the tasks. Whilst students attempted the tasks teachers observed them and scored group plans and actual performances of the hands-on activities. Additional assistance was, however, necessary for monitoring and helping the students with the tasks when they were experiencing difficulty, particularly with the equipment. The researcher provided the necessary assistance. Even with such additional assistance, it was still difficult for the teachers to attend to each group of students adequately, as noted above, without other groups becoming anxious about losing time and finishing the task.

The availability of adequate equipment to enable students to be assessed fairly through performance tasks is another setback for performance assessments. Administering performance assessment tasks to groups of students eased the problem of equipment. For Swaziland the problem of equipment and other resources is further compounded by the situation of orphaned and vulnerable children (OVC) who are unable to pay fees. The Government of Swaziland expects all children to be accepted into schools and pays a nominal fee for the OVCs. The paying process is administered at a national level and is accompanied by delays, so the purchasing and acquisition of teaching resources may be hampered.

## **Challenges for performance assessment**

The inclusion of performance assessment as part of school science assessment models is a recent development in the history of educational assessment, even though performance assessments have been in use for some time in other fields. Teachers and examination authorities have not readily embraced their use. Insufficient knowledge on their use by teachers to fairly assess students' performance, unsuccessful experiences

and/or inconclusive executions of performance assessment is thought to be responsible for their poor acceptance by teachers (Brualdi, 1998). Other reasons for the apparent lack of widespread use of performance assessment, particularly for large-scale national examination bodies, include issues of reliability, generalisability of performance in one task to other tasks, and costs in respect of time for production and administering tests, and resources (Linn and Gronlund, 2000). There is undoubtedly no single assessment model that can appraise science learning experiences in totality. There is always some limitation that will affect the suitability of an assessment model for a particular purpose. It is possibly due to these problems that performance assessments have been considered viable assessment approaches much later in the last century (Stiggins, 1995).

Performance assessments are particularly vulnerable to reliability problems that relate to content sampling, standardisation and scoring. Performance assessment techniques measure understanding of content by students in greater detail, but the scope of curriculum goals explored is limited to a few assessment tasks. The breadth of coverage observed in standard or objective-type tests (structured short-answer and multiple-choice tests) is traded for depth in performance assessments. The lack of adequate coverage in curriculum topics assessed can give distorted information about student achievement. For example, very high or low scores can be allocated while the tasks used emphasised certain topics or concepts over others. The use of fewer tasks in performance assessments is dictated by the degree of complexity of the tasks used which require more time. In order to obtain a more comprehensive picture of students' knowledge and skills, a substantial number of performance tasks are necessary. This would mean constructing a number of different performance tasks per subject over a longer period of time (Linn and Gronlund, 2000; Roberts and Gott, 2004; Sanders and Horn, 1995). This extreme scenario may not be necessary because advocates of performance assessment are merely negotiating for reconsideration of assessment models that include the assessment of curriculum goals omitted by the standard assessments.

Researchers engaged in debates on the use of performance assessments raise a few concerns regarding criticisms against the validity and reliability of these assessments. Moss (1992) observes that traditional approaches and criteria for validity in research and assessment do not seem appropriate for handling the validity problems raised on the subject of performance assessments. The criteria currently used to judge validity, reliability, and

generalisability of assessments become problematic when applied to alternative assessments. In performance assessment, students are required to integrate multiple skills and knowledge, and produce complex responses that cannot be effectively judged using validity criteria designed for objective tests and less complex responses. Moss (1992) further challenges researchers to find appropriate criteria to support validity issues in performance assessment.

Generalisability of results is another problem. The performance of students on a small sample of tasks cannot be generalised to other tasks or the general performance of the students. A good performance in one task does not necessarily mean that the same student will demonstrate similar abilities in a different task (Popham, 1999; Sanders and Horn, 1995; Shavelson *et al.*, 1991). Performance is task dependent. Again, multiple tasks would be required to enable generalisations from performance assessments results. Generalisability is a problem for summative assessment, which takes the overall achievement of the student into consideration. The apparent task dependability of performance assessment is a reality we have to work with because some subject content is concrete and can be easily understood while other areas are abstract and therefore more difficult to understand. The intellectual demands of performance tasks are content dependent.

In the interest of ensuring more efficient education for students, educators need to broaden approaches to assessments. The observations highlighted above support Gott and Duggan (2002), and Gipps and Stobart (2003) argue that multiple assessment formats are necessary to give students adequate opportunities to demonstrate their understanding and ability to apply their knowledge. The assessment situation should not be seen as an either/or situation, but one where the best complementary assessment approaches are used to appraise students' learning experiences. Performance and standard assessments should be used in a collaborative way. The shortfalls of performance assessment may be severe for large-scale standardised assessments, but the use of these assessments to whatever extent in school-based assessment ought to be considered. Moss (1992) argues for the use of less standardised performance assessments where teachers (and students) set their own performance tasks and standards and criteria that would apply to their situation. Some marketing of the new assessment formats and initial training would be necessary for the teacher. This would also call for adjustments in the assessment practices in

schools to accommodate the new forms of assessment and not to replace established ones. The negative impact of the exclusive use of standardised forms of assessments has been experienced and there is no need for another negative experience involving performance assessments.

## **Conclusion**

This chapter has presented a brief overview of the literature on the limitations of standard assessments and the need for considering performance assessment. Assessment approaches used in Swaziland are also discussed to show the conspicuous absence of practical assessment of skills at the junior secondary level while practical tests are being conducted at the senior level. Some findings on the use of performance assessment are also discussed and are summarised below.

The use of performance can improve student learning from practical work because students will work with more seriousness and commitment where there are marks to be scored. In the same vein, the tasks focused students' attention on practical activities in anticipation of obtaining high marks during the performance assessment tasks.

Students also enjoyed working on the task. For those who did not get many opportunities to engage in practical work, the performance task was a chance to do things practical and possibly confirm what teachers had told them. The tasks were initially difficult and challenging for the students, but they appreciated the exposure to another way of testing and thinking.

Administering performance assessment tasks has several advantages, as well as disadvantages. Students appreciated working on tasks in groups because they shared ideas and learnt from one another. Students who missed something during lessons could be helped by explanations from fellow students. The concerted efforts of the group produced good results and scores on the tasks, which was encouraging for the students. Students also developed affective aspects of working cooperatively and collaboratively with one another in teams, such as communication and listening skills and helping one another. Participation increased compared to other practical activities, but still not all students participated. Also, not all students could manipulate the equipment at the same time. Another problem was that in some instances good ideas could be ignored if the source was not aggressive enough in selling the idea.

Interactions between teachers and students also contributed to improved scores. Some groups, however, wanted too much attention from the

teachers, making it difficult for the teacher to adequately attend to all the groups in the class. This problem contributed to delays in the other group completing the task. Other delays were due to students not initiating the task as soon as they were advised to, and group discussion taking too long before reaching agreement.

From the discussions above it is clear that no single assessment technique is infallible. Performance assessments have their strengths and weaknesses, just as the tried and tested standard assessments do. The effect of some of the apparent drawbacks for the implementation of performance assessment task could be reduced with frequent use of the approach so that students can become familiar with it. Performance assessments can be made to work; if not for large-scale standardised assessment then for classroom science assessment. It is therefore important for education and assessment practitioners to make use of multiple assessment approaches to appraise student learning. Standard and performance assessments should be used in a complementary way to assess simple and complex learning outcomes. However, further research is still needed to inform decisions about the use of performance assessment in school science and improve their validity and reliability through the development of relevant criteria.

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## Appendix 1: Electricity Practical Performance Tasks

Names of Group Members for Group Number: \_\_\_\_\_

Date: \_\_\_\_\_

*Instructions: You will work on this practical task in groups. You are allowed to discuss among yourselves in your group and you may check with the teacher for some information you may need. Extra writing paper is provided.*

### Assessment task 2

In this activity you will work in your group.

- i) You will assemble a circuit that includes a voltmeter and ammeter.

You will use the circuit to

- ii) measure the voltage across different pieces of wires, and
- iii) measure the current through the different pieces of wires

You will then

- iv) calculate the resistance of each of the given wires.

### Material provided to each group

- 3 x 1.5V cells (when you are ready)
- 1 circuit board
- 1m long pieces of wires marked H, I, J, K
- 1 voltmeter
- 1 ammeter
- switch

### Procedure

1. Use a separate sheet to write out a plan of how you are going to connect the circuit and how you will **record your results**. Show your plan to the teacher.
2. Set up your equipment and use it to measure
  - i) the current passing through the wire and
  - ii) the voltage across the same wire
3. Record your results in an appropriate table
4. Calculate the resistance of each piece of wire.

**Questions**

- a) List the wires in order of increasing resistance beginning with the wire with lowest resistance. (2)
- b) Thembi wants to design a torch. She asked her father for some wires for her torch project.
  - i) Which of the wires you tested could Thembi's father give her? (2)
  - ii) Why do you think this wire would work best for Thembi's project? (2)
- c) Suppose you want to work on a project to show that a 'current carrying wire' can be used to boil water.
  - i) Which wire would be most suitable for your project? (2)
  - ii) Why would the chosen wire be most suitable? (2)

# *9. Localising the Junior Secondary Science Curriculum in Lesotho: An Attempt at Integrating Technology and Science*

Lits'abako Ntoi, Lorna Holtman,  
Meshach Ogunniyi and Svein Sjøberg

## **Abstract**

Curriculum and assessment in many African countries have most often been shaped by international influences. In many countries where curricula are generally imported, the alignment between curriculum instruction and assessment has been difficult to achieve. As a result, changes in curricula have not been able to meet these goals. Owing to the Lesotho government's aspiration to provide all Basotho with basic education and the need for Lesotho to depart from its educational colonial past, Lesotho attempted to localise its curriculum. This resulted in a science curriculum which has incorporated technology.

This chapter describes how the science curriculum with a technology emphasis was developed in Lesotho. It includes a brief outline of the reasons which led to the development of such a syllabus. The chapter also deals with the literature on science and technology in the school curriculum. It further highlights the process of the Lesotho science technology syllabus development with examples from the syllabus and the textbook written for the syllabus. The chapter ends with a discussion and conclusions on issues, which are raised, by

both the literature and the process of syllabus development, in the context of Lesotho. It is argued in this chapter that incorporating science and technology is a worldwide phenomenon and indeed a curriculum issue. As a result of localising the ideas related to the incorporation of science and technology, science curriculum developers need to be familiar with the global perspectives so that they can localise the ideas related to the integration of science and technology efficiently in their own context.

## **Introduction**

Lesotho is a small landlocked country, located south of the Sahara, with an area of 30 335 square kilometres. It is situated between latitudes 28 and 31 degrees South and longitudes 27 and 30 degrees East. It is completely surrounded by South Africa and is largely a mountainous country. All of its territory lies above an altitude of 1000 metres. Its population is about 2.2 million (Ministry of Trade and Industry, Cooperative and Marketing, 2004).

The main source of income for Lesotho is the export of garments from manufacturing industries and royalties to the Lesotho Highlands Water Project, which exports water to South Africa. Lesotho is regarded as one of the poorest countries in the world and is ranked as 127th of 174 countries on the UNDP's Human Development Index. The economy of Lesotho began to decline significantly in 1998 as a result of political unrest. Among other factors that contributed to the decline, was drought, retrenchment of Lesotho mineworkers from the mines in South Africa, and poor performance of state-owned utility companies. All these happened around the same time as the political unrest (Ministry of Education, 2004).

The government of Lesotho envisages the provision of basic education to all Basotho as the central goal towards enhancing social and economic development (Ministry of Education, 2004). According to Lewin (1992), human resource development has become a central feature of most national development strategies; with the emphasis more often than not being on the acquisition of scientific and technological skills and capabilities.

According to Ogunniyi (1996), the link between science and technology and economic growth is a complex one. There is, however, evidence to show that there is a strong link between science and technology and economic progress. Hence the Ministry of Education Lesotho's vision for 2005–2015 is: 'to achieve scientifically, technically and technologically well educated and functionally literate Basotho by the year 2020' (Ministry of Education 2004: 2)

## *Localising the Junior Secondary Science Curriculum in Lesotho*

The current reforms in science education in Lesotho are linked with the government's aspiration to provide all Basotho with basic education and with Lesotho's departure from its colonial past. Lesotho, like many Anglophone African countries, inherited a British education system. Assessment and curriculum reforms which took place in the UK in the 1980s, however, made it difficult for countries following this system – Botswana, Lesotho and Swaziland – to cope with these reforms. Some of the reasons for the inability of these countries to cope with the change include the fact that the reforms were unwieldy and were tailored as a response to the domestic politics and socio-economic realities of the UK. These realities do not necessarily align with those of many African countries.

As a result of educational reform in the 1980s, countries like Botswana, Lesotho and Swaziland began to initiate localisation of their curriculum and assessment systems. In 1989 Lesotho embarked on localising its curriculum and assessment. Localisation of assessment-related tasks began in 1989. Later, in 1994, the review of all secondary curricula followed. The Science Panel was charged with the responsibility of reviewing the science curriculum. Upon reviewing the science curriculum the Panel aimed at closing the gap in content, which was observed to exist between JC (GRADE 10) and O-Level (GRADE 12). It also tried to bring science content into the context of Lesotho, as well as include issues of technology and environment. The revised science syllabus has resulted in a new syllabus emphasis, one of which is the inclusion of technology. The aim of including technology centres mainly on the need to improve the acquisition of scientific and technological skills and capabilities, which are perceived in many developing countries as central to human resource development. The revised curriculum for junior secondary was introduced in all Lesotho schools in 2002. The Science Panel experienced a conceptualisation problem with regard to including technology in the science curriculum. However, technology has been included in the new science syllabus and is currently taught in all secondary schools.

### **What is technology?**

Technology has multiple meanings and encompasses many connotations. Its meaning depends on the context in which it is used. It can be used to describe a certain type of knowledge, like design and building (Layton, 2006). In some cases, technology refers to types of technologies, e.g. food

technology, material technology and space technology. It can also be used in describing artefacts like the sewing machine, the computer or the hoe (Jenkins, 1996). The meaning of technology also shifts across languages. For example, 'technology' has two meanings in French. It can refer to organised knowledge and skills (technologie) or it can denote scientific knowledge (technique) (Gardner, 1994). A popular dictionary definition of technology is: '...applied science, technical method of achieving a practical purpose, the totality of means employed to provide objects for human substance and comfort' (Merriam-Webster, 1998: 1188).

There are many definitions of technology which associate technology with human welfare (Layton, 2006; Ogunniyi, 1996; *Webster's New Collegiate Dictionary*, 1998). In general terms, technology is taken to affect human life, as it has influence on the economy, politics and social relationships (Raaf and De Vries, 1987). However, Sjøberg (1995:8) argues that technology is not always directed as human welfare:

The war technologies have been mentioned as examples of technologies that certainly do not aim to meet human needs. And for the modern technologies like home electronics, one may well describe this as a development where the characteristic is not to meet needs, but to create new 'needs' in the market.

The different meanings attached to technology also depict the views about technology. Gilbert (1992) indicated that there are three points of views held about technology. These are: the 'human view', which sees technology as responding to and serving human needs; the 'titanic view', which takes technology to be heroic and attempting to control nature; and the 'satanic view', in which technology is used to produce destructive machinery and environmental problems. Generally, technology is a fluid term, and its meaning depends on the context in which it is used. Hence, Bungum (2003: 5) states:

The concept of technology is familiar to most people and brings about a variety of associations. Yet, formulating a precise definition of the concept or a functional description that captures the essence of these associations is not a straightforward matter.

## **Technology education**

As a result of the diversity in the meanings of technology and differing views to it, there is no common usage and understanding of the word 'technology' (Sjøberg, 1995). It is not surprising therefore that the phrase 'technology education' is also open to many interpretations. Parker and Albert (1998) indicate that most people, especially those who are not involved in education, associate technology education with computer education. Others relate it to information technology. Medway (1993) indicates that some of the meanings of technology found among primary teachers include: up-to-date craft work, applied science, something which has wheels, making models, problem solving, and acquainting learners with industry. Gardner (1994) reports on several studies in which it was found that secondary teachers took technology to be the application of science. In their research and development of Project 'Physics and Technology' in the Netherlands, Raat and De Vries (1987) found that secondary learners associated technology with machinery.

The factors complicating the inclusion of technology education does not only emanate from its meaning, but technology education like many other curriculum issues is faced with many competing influences. Layton (1993), Gilbert (1992) and McCormick (1992) indicated that there are many stakeholders in technology education who have different opinions about the reasons behind the inclusion of technology in the school curriculum. Among the stakeholders in technology education there are economic instrumentalists, professional technologists, sustainable developers, girls and women, the defenders of democracy, and liberal educators; all of whom argue for the inclusion of science and technology from their own camps.

Owing to the varied understandings and perspectives that stakeholders in technology education have, it has developed in different directions globally. According to Treagust and Rennie (1993) and Allsop and Woolnough (1990), technology education has developed along four different directions. The first direction is dominated by crafts subjects, the second focuses on high-tech advances in computers and electronics, the third presents technology as an engineering course at secondary school, and the fourth presents technology as the subset of science education. De Vries (1994) classified the directions in which technology education has developed in a similar manner, but extended the list of the different ways in which technology education has developed. His list of approaches

consists of: the craft-oriented approach, the industrial production approach, the high-tech approach, the applied science approach, the general technological approach, the design approach, the key competence approach and the science/technology/society approach.

The understanding that technology teachers or science teachers and curriculum developers bring into the teaching of science and technology does influence the way they treat and talk about these fields in their classrooms and curriculum statements. It is, therefore, important to understand the relationship between science and technology and the different ways in which countries have introduced technology into the school curriculum. According to Gardner (1994), there are four generally-held positions on the relationship between science and technology which have an influence on curriculum. These are technology as an applied science view, demarcationist view, materialist view, and interactionist view.

Seeing technology as an applied science asserts that science precedes technology. That is, technology capability grows out of scientific knowledge; or scientific knowledge generated by scientists provides a basis for the development of technological products (Gardner, 1994, 1999). The following statement illustrates this view:

Basic research leads to new knowledge ... it creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are found on new principles and conceptions, which in turn are painstakingly developed by research in the purest realms of science. (Bush, in Gardner, 1994)

The technology as an applied science view is generally found in curriculum statements, instructional content and teachers' opinion; just as it is found in public statements like the one above. As an approach in the science-technology curriculum, it has some limitations. First of all, it tells a limited story about the artefact. For example, the operation of the scientific principle is often explained in terms of the scientific concepts that appear in the topic under discussion. This is usually incomplete. Furthermore, it neglects design skills, which are normally not considered scientific knowledge. The motivation for technology under this view is normally to enhance understanding of the scientific principle through a broad range

of interesting applications of real life and has nothing to do with design. Another consequence of the technology as an applied science view is that it leads to misconceptions of history by taking the technological artefact out of its historical developmental context (Gardner, 1994, 1999).

The demarcationist view suggests that science and technology are different fields, with different goals, using different methods. Science is taken as a subject that generates knowledge, which is analytical and associated with scholars who seek understanding. Technology deals with design, making and improving technological artefacts, materials and systems and products that are needed to meet human needs. Supporters of this view show that through historic times, technology has developed independent of science. Currently it is difficult to draw the line between science and technology, as most scientific research happens together with technological developments. Supporters of this view argue that there are many artefacts, which were developed by the process of transmission and evolution of craft knowledge. These artefacts were developed without scientific knowledge (e.g. pottery, plumbing, brewing, windmills, sailing of ships and food preservation). The demarcationist view does not always clearly say there is a difference between science and technology. Textbooks and other curriculum materials that emphasise pure sciences, however, emphasise that there is a difference between science and technology. Some design courses focus on design almost exclusively and ignore the opportunity to develop science content knowledge when possible or appropriate. These courses also support the same arguments (Gardner, 1990, 1994, 1999).

The materialist view suggests that technology precedes science. It asserts that technology is historically and ontologically older than science. Many arguments are put forward for this argument. Examples include the extraction of metals, which came before the understanding of the chemistry associated with them. Optical instruments were also developed before the formulation of the laws of refraction, which explained their operation. This view emphasises the fact that experience with tools, measuring instruments, and so on is necessary for the development of scientific knowledge. Curriculum founded upon these arguments provides opportunities for technically skilled learners to acquire relevant scientific knowledge (Gardner, 1990, 1994, 1999).

The interactionist view asserts that the technologists and scientists are groups of people who learn from each other. Those in favour of this view

argue that technologists can learn from science research, and scientists can learn from existing technological artefacts by examining them and improving on them. Sometimes the interaction happens concurrently with the rise of major research centres in some fields, such as electronics, biotechnology, computing and many more. In modern times, it is very difficult to separate science from technology (Gardner, 1999).

### **Approaches to the teaching and learning of technology**

Layton (1993) and Fensham (1988) indicate that the science of the early-1960s was 'pure', but the curricula which followed incorporated technology to some extent. This was done in the form of applications or illustrations of science in action. Although this has been done in general terms, the literature does show that the incorporation of technology into science has been done in different ways. Layton (1993) shows four different approaches in which technology and science have been incorporated: science and/or with technology, science of technology, science for technology, and science–technology–society (STS). Gardner (1990) suggests five approaches: technology as an illustration; the cognitive motivational approach, technology as an artefact, technology as a process, and science, technology and society.

Technology as an illustration is the same as science and/or with technology. In this case, the technological applications are presented after scientific concepts have been treated. For example, students are taught electromagnetism in the usual classroom/laboratory atmosphere and then they examine the electric bell as an application to find how it applies the electromagnetism concepts. This approach is illustrated in programmes such as Physics Plus, Chemistry Plus, and Biology Plus. It is further illustrated in physics textbooks, such as PSSC by Haber-Schaim, Dodge and Walter (1986) (Gardner, 1990; Layton, 1993).

The cognitive motivational approach, according to Gardner (1990), presents technological applications very early in the instructional sequence in order to capture students' interest in the topic and then teach the scientific concepts. The aim is to attract student's interest and the early applications can sometimes be treated superficially. This approach is similar to what Layton (1993) calls science of technology. He suggests such application leads to context-based approaches. Examples can be obtained from Salter's Chemistry in Britain and Chemistry in the Community (Chem. Com.) in the USA.

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Technology as an artefact, as explained by Gardner (1990), involves disassembling artefacts in order to understand the workings of the different parts. They could be real or simulated artefacts. Although the scientific concepts are still developed through this method, the central issue is to study artefacts as systems. The scientific concepts to be learned are directed by what the artefact can offer. An example of this approach is when children are asked to disassemble household artifacts in order to understand how they work.

Technology as a process is similar to what Layton (1993) terms 'Science for technology'. It is quite different from the other described approaches in that it emphasises the development of technological capabilities. In this approach science is a resource for enhancing problem solving, i.e. inventing, designing, making, etc. Scientific ideas are only relevant if they contribute to the development of these abilities.

Science–technology–society or Science, technology and society (STS) focus on societal issues and topics with a strong science and technology dimension. The main aim of this approach is to contribute to technological education through technological awareness; that is, 'awareness of personal, social, moral, economic and environmental implications of technological developments' Layton (1993: 43). Gardner (1994) is of the opinion that this approach places less emphasis on technological capabilities and science content, focusing instead on the problematic nature of scientific knowledge.

The literature shows many projects that have attempted to produce STS materials. Examples of such projects are the PLON materials developed in the Netherlands, ALCHEM developed in the 1970s by Alberta teachers led by Jenkins, and Science Plus, developed by McFadden in 1986. Further examples include Innovations: The Social Consequence of Science and Technology (IST), which is curriculum material developed by the BSCS group in Colorado, and others (Fensham, 1988; Layton, 1993). However, in most cases, STS has remained an option or addition to science.

According to Fensham (1988), some of the factors that have contributed to this state of affairs, are: (1) STS issues usually involve science from different science disciplines, which do not normally appear that way in the school science curriculum. For example, an issue like 'ionising radiation' could traditionally be a physics topic, but under STS it includes other disciplines such as chemistry and biology – especially if it deals with issues such as the ozone layer. (2) In many countries science teachers are specialists in their

science disciplines and do not have the knowledge and the confidence to engage with concepts or arguments that involve economics, politics, religion and so on, which are required in dealing with STS. (3) In most cases the undergraduate courses do not deal with controversies in pure science, and the teaching approaches hardly include discussions on such controversies. As a result, teachers are not comfortable dealing with such arguments.

As a result of the problems facing STS, various approaches to the development of STS materials have emerged. These approaches can, according to Fensham (1988), be classified according to what is regarded as the 'knowledge of worth' or which of the STS components determine the content to be learnt. Among the STS materials there are those whose 'knowledge of worth is determined by either technology, by society or by science' (1988: 347).

In the technology-determined approach, the 'knowledge of worth' is determined by technology. Traditional science content is included, but it is not regarded as important. In the science-determined category the choice of topic to be studied is based on the sequencing of traditional science topic approach. Their concept and principle remains the same. The depth of treatment of added STS topics would vary and can be optional. The society-determined approach happens when the societal significance of the topic determines the science and technology that are to be included in the materials.

Hofstein and Aikenhead (1988: 359) indicate that there is great interest in STS courses, but there are associated problems and concerns. Among the problems, they highlighted the following:

- The lack of clear definition of STS.
- A lack of theoretical structure.
- High esteem accorded to the disciplines of physics, chemistry and biology in their traditional form.
- The unfamiliarity of teachers with the required teaching strategies.
- The nature of STS materials that tends to be fluid and tentative when compared to the 'clear-cut' information style of traditional science courses.
- Inadequate curriculum development and implementation procedures.
- Inappropriate techniques and procedures for pre- and in-service teacher training.

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- A paucity of teaching materials.
- Opposition by boards of examinations, higher education and politicians.
- The general conservative nature of educational systems.

### **Integrating technology into the Lesotho science curriculum**

It has already been mentioned that the introduction of technology into the Lesotho junior science curriculum was motivated by the need to promote scientific and technological literacy among all Basotho citizens. In the context of Lesotho, scientific and technological literacy are recognised as an indispensable component of economic growth. As indicated in the introduction, the Science Panel tasked with the review of the localised curriculum decided to include technology into the science curriculum at junior secondary level.

In an attempt to include technology and understand what constitutes inclusion of technology into a science curriculum, the Science Panel included persons from the Department of Technology, the Department of Mining and Geology, the Technical School of Lesotho, and the Department of Appropriate Technology. Different resource persons brought different perspectives of the meaning of technology to the panel. The science panel further undertook a study tour to South Africa. The aim was to find out how other countries dealt with the issue of technology and to understand what inclusion of technology encompasses. Despite all these efforts, it was difficult for the Science Panel members, who are mostly science educators, to come to a common understanding of technology inclusion into science. The panel did, however, make progress with integrating technology into the science syllabus to the best of their ability and wrote textbooks for the syllabus.

The inclusion of technology meant firstly developing the subject objectives, which address the national objective of promoting scientific and technological literacy. Seventy-one per cent of the Lesotho science syllabus general objectives that related directly to the inclusion of technology were developed, for example:

- I have developed awareness and appreciation of scientific and technological activities, and interdependence of scientific, socio-economic and technological changes in Lesotho and other countries.

- I have acquired scientific knowledge, skills and attitudes to solve problems related to socio-economic and technological changes.
- I have developed the ability to apply appropriate scientific and technological skills for survival in everyday life and new situations. (Ministry of Education and Manpower Development, 2002: 5)

The syllabus itself separates the three science disciplines. That is, one can recognise the biology, physics and the chemistry components within the syllabus document. The science topics within these disciplines are the usual traditional science topics and are sequenced in a normal way. Each of the general objectives, like number one above which reads: 'have developed awareness and appreciation of scientific and technological activities, and interdependence of scientific, socio-economic and technological changes in Lesotho and other countries', were further broken down to specific objectives. The following are examples of specific objectives that were developed from the first general objective:

- Identify scientific and technological activities going on in the environment (home, school, community, globally), Lesotho and other countries.
- Identify the effects of scientific and technological changes on the socio-economy of Lesotho and other countries.
- Describe the effects of scientific and technological changes on the socio-economy of Lesotho and other countries.
- Describe the importance of scientific and technological activities in Lesotho and other countries, relate scientific and technological activities to socio-economic and technological change, describe the interdependence of scientific, socio-economic and technological changes. (Ministry of Education and Manpower Development, 2002: 5)

These specific objectives were then classified according to the three-science discipline (biology, physics and chemistry) that the specific objectives were perceived to be serving. The learning outcomes or classroom objectives for different science disciplines were then developed. Examples of such learning outcomes from physics under the topic 'Waves' are shown in Table 1.

**Table 1: Electricity learning outcomes**

<b>Learning outcome</b>	<b>Content</b>
1. Describe the production of sound and water waves	1. Types of waves: sound, water, electromagnetic, sound waves, water waves, radio waves, microwaves, infra-red rays, visible light, ultra-violet, x-rays and gamma rays
2. State examples of waves	2. Producers of waves: X-rays, radio, transmitter, sun hot objects, radioactive substances, microwave oven
3. Identify producers and detectors of waves	3. Detectors of waves: photographic film, aerial, satellite
4. Describe waves as longitudinal and transverse	4. Longitudinal wave – sound. Transverse waves – water wave, electromagnetic waves
5. State types of electromagnetic waves	5. Parts of electromagnetic waves
6. Identify uses of electromagnetic waves	6. Uses of electromagnetic waves
7. Relate ultrasonic and use of ultrasound scanner to audible and inaudible frequencies	7. Detection of ultrasound and ultrasonic sound

In developing the science-technology syllabus, the Science Panel first drafted a mission statement, which reflected the national goals. From the mission statement the panel developed the general objectives or broad statements of intent. This was followed by the development of specific objectives, which in turn were meant to guide the selection of content, approaches to the teaching of the syllabus, and the type of assessment of learning outcomes. After developing the specific objectives, the panel chose the content and sequenced it to produce the scope and sequence chart. This chart normally shows how the content flows across the different levels of secondary education. The scope and sequence chart guided the development of the intended learning outcomes. The learning outcomes dictate what is to be taught in class in specific terms. This process is summarised as in Figure 1.

**Figure 1: Development process of the syllabus as done by the Lesotho Science Panel**

National aim → Subject aim → General objectives → Specific objectives  
→ Scope and sequence chart → Learning outcomes

After the development of the learning outcomes the syllabus document was completed. The next stage was the writing of the textbooks. The textbook chapters brought together content from different science disciplines. The content on waves, which is driven by the learning outcomes shown in Table 1, appeared under the topic 'Science around us'. The chapter included the content shown in Figure 2 below.

**Figure 2: Content included in the topic 'Science around us'**

• Useful resources for humans • Separating mixtures of liquids • Plants as a resource • Soil • Pollution • Plants and the environment • Endangered species • Water • Water and water pressure • Filtration – separating solids and liquids • Metals and minerals • Chromatography • Invisible science. (Mpetla *et al.*, 2000: 1)

Waves were specifically dealt with under 'Invisible science'. This section dealt with the electromagnetic spectrum, placing emphasis on X-rays, visible light, infrared radiation, ultraviolet radiation, gamma rays, radio waves and their application in everyday life for giving examples of technological artefacts associated with them.

## Discussion

According to Layton (1993), science-technology-society (STS) as an approach to the incorporation of science and technology focuses on societal issues and topics with a strong science and technology dimension. Its aim is to contribute to technological awareness, which is awareness of personal, social, moral, economic and environmental implications of technological developments. In terms of its objectives, the Lesotho science syllabus appears to be in line with the STS approach. However, this changes drastically as the process of syllabus development moves towards what should actually be taught in the classroom (learning outcomes). The learning outcomes emphasise the science content to the extent that if one

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were to use the learning outcomes on their own for teaching you would end up teaching the normal science content. The 'knowledge of worth' as Fensham (1988) puts it, is science.

The Lesotho science syllabus separated the sciences into biology, physics and chemistry. An STS approach encourages integration, and separating the science subjects therefore contradicts this approach. This is because STS issues, by their nature, integrate content from different science disciplines (Fensham, 1988).

There is an observable mismatch between the textbook and the syllabus. There is an effort by the authors of the science textbook to use the thematic approach, as one can see from content arranged in the book chapters. The syllabus, on the other hand, has remained with the traditional topics with the science disciplines separated and learning outcomes focusing on science content.

The Lesotho science and technology syllabus needs to relate the general objectives with the learning outcomes, such that they address the same educational goal. If the aim is to incorporate technology with science, the syllabus through all its statements should be seen to be addressing that. In other words, the learning outcomes which emphasise science content are not working towards achieving the set goal of integrating science and technology. Secondly, there is a need to align all curriculum materials. For example, the textbook which shows the thematic approach should be supported by the syllabus which adopts a similar approach in that it deals with science content thematically and integrates content across the science disciplines.

### **Conclusion**

The discussions indicate that the problems of incorporating science and technology into the Lesotho science syllabus could be associated with curriculum development. The technocratic perspective to curriculum development – and, consequently, the curriculum design model adapted by the curriculum developers – might have contributed to lack of success in the attainment of the goals of the curriculum. The technocratic perspective to curriculum development assumes curriculum development to be a technical undertaking. This assumption makes curriculum developers focus more on the process than on the different steps involved in the process. Consequently, there is an observable mismatch between the syllabus objectives and the learning outcomes. Based on this argument, the process of planning

curriculum around inclusion of technology in the school curriculum would not easily fit into a step-by-step procedure, which is highly technical. This was the case in the development of the Lesotho science curriculum. The process was highly technical. As a result, in trying to state the learning outcome in behavioural terms, I believe many important learning outcomes which relate to technology have not been included.

Secondly, it was indicated at the beginning of this paper that the curriculum developers did not have common understanding of what technology inclusion meant. I believe lack of understanding contributed significantly in the mismatch, which is observed between objectives, learning outcomes and the textbook.

Curriculum innovations usually follow global trends. Consequently there is a substantial body of research on the innovations related to technology education. It is therefore recommended that the curriculum developers in Lesotho should familiarise themselves with this literature so that they become acquainted with trends, debates and pertinent issues in technology education.

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# *10. Practice-Related Underachievement in Science Education: The Case of Malawi*

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## **Abstract**

Researchers examining the problem of poor performance in science subjects in developing countries in Africa have focused attention on students' cultures, teachers, world-views, and the students themselves. It is, however, presented in this chapter that the learning styles and students' attributions of success or failure in learning science that students adopt in the course of schooling may also have adverse effects on students' performance in various subjects, including sciences. In this study we examine quality of learning and attributions of success or failure among highly selected students in secondary schools in Malawi against the background of worsening performance in science subjects and a history of poor performance in science that stretches to the early 1940s.

For the purposes of this study, 1 300 secondary Class 3 students were drawn from 15 schools selected on a stratified random basis in the three regions of Malawi, each of which completed a learning skills and practices questionnaire with most items adapted from the literature. Four students from each school were selected on the basis of good performance in physical science and were interviewed about their understanding of the nature of science, learning skills they use in learning science, and their attributions of success or failure in learning science. The results indicate that although the students were highly

selected, their knowledge of science is still of the positivistic formulation. Science, to most of them, is 'the study of living and non-living things'. It has little to do with their everyday lives. The students knew no way of learning science other than reading, listening and working out exercises. Compared with similar students in the literature, the performance of Malawian students in the questionnaire we administered suggests that there may be factors related to their learning practices that could be impeding their success in their learning of science. The questionnaire and interview data indicate that the students do not see themselves as an important factor in their success. The students consider their teachers to be the most important factor that determines their level of performance. According to students, other factors that determine their level of performance are availability of books and science equipment. The students thus seem to consider themselves as contributing little to their success or failure.

Failure of the students to see themselves as an important factor in determining their success in learning may be indicative of lack of personal initiative in their learning. Absence of student-initiated exercises in students' exercise books seems to support this conclusion. We propose that a detailed investigation of the causal links, if any, between students' learning styles and attributions and performance in science, be conducted to determine the roles that these variables play among these students.

## **Introduction**

The science education literature is replete with reports and discussions of underachievement of students in science subjects. It is generally maintained that the general shortage of material and human resources for teaching science, students' negative attitudes to science, and their lack of commitment to learning science are some of the factors contributing to this problem. In the case of students from Sub-Saharan Africa additional factors such as African world-view, African culture and the difficulty of learning science in a foreign language are also mentioned. The nature of these factors is such that there is seemingly little that teachers can do to alleviate this problem. Teachers can neither provide the human and material resources required, nor change students' world-views. The literature thus paints a picture of helplessness and hopelessness in so far as the problem of poor performance in science in developing countries in Africa is concerned.

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There is, however, one dimension of the poor performance problem in science that, although it is susceptible to teacher intervention, tends to be neglected in the science education literature. This is the dimension of learning styles of students during non-school hours. Students' learning styles may be related to science education policies that a country is actually pursuing or has pursued in the past. With regards to this, Chipembere (2000: 73–74) notes that, 'once certain traditions are established ... they persist many years afterwards'. Ogunniyi (1986: 119) portrays the situation in most African countries at the end of the first decade of independence:

The embryonic development of science education will show in every cell of our development plans that in most African states today there are many undeveloped decision makers and advisers on science. All over the continent one sees all sorts of slipshod and haphazard efforts at planning and implementation – crash programs for the training of science teachers and laboratory technicians, crash erection of classrooms and laboratories, crash implementation of a new policy on education, and so forth. Whether or not positive results will emerge from such activities is totally irrelevant to many a government. After all there are 'intellectuals' who will prophesy, an inevitable success, adequate planning or not.

It is not that positive steps towards development of science and technology have not been taken; it is that steps taken have consistently lacked the scientific approach. Various hesitant and ambiguous attempts at planning and implementation of science education programs have been made, but these have practically always been improvised and rarely well implemented.

The ill-conceived and implemented policies or development plans that Ogunniyi refers to in the excerpt above, may have enduring effects on students' learning. The apparent lack of concern for the consequences of the policies being pursued may also have a long-lasting effect on the quality of learning science subjects. Hence, the policies that countries have pursued or are pursuing may promote underachievement in science subjects in schools. This paper adopts Schaffer's (1996) definition of policy as the purpose for which people associate in the polis. In education, policy in this sense means the general direction for optimising the search for

the best means to realise given objectives. This chapter explores students' learning styles and concepts of science and science learning against the background of relative neglect of primary education relative to secondary education, and reduction of periods for teaching science from five to two a week. These policies are discussed briefly before presenting the study.

### **Relative neglect of primary education**

On the eve of independence in 1964, Malawi was served with two conflicting proposals for the improvement of education. One proposal tendered by the Phillips Commission advised the government to begin by improving the quality of primary education. The Phillips Commission maintained that:

Much could be done to improve methods of selection for entry into the secondary schools, but no great improvement in work at that level is possible until the general quality of those selected has been raised. (Phillips *et al.*, 1962: 57).

According to the excerpt above, improvement in the quality of education received by primary-school leavers is a prerequisite for improvement of education at secondary level. Selection of students, however stringent it may be, cannot ensure success of work at secondary-school level. Contrary to the advice of the Phillips Commission, the Johnson Survey Team advised the government to ignore further development of primary education for the time being, and concentrate on further development of secondary education. According to the Johnson Survey Team:

The government's announced objective of full primary education for every child is an admirable long-term goal. It should be adhered to although caution is required and emphasis must be on steady progress over a long period of time. Otherwise Malawi can and will exhaust its educational resources on the kind of mass literacy which will never attain a productive level for the economy, never man essential government posts, and never prepare the available talent for the professions and creative pursuits. This is a painful decision, but further development of primary education is less important than further development of secondary education for the immediate future. (Johnson *et al.*, 1964: 7).

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In accordance with the advice contained in the excerpt above, the Malawi government abandoned its plans to develop primary education and concentrated its development efforts on secondary education. The Johnson Survey Team also advised the government to continue selecting students to be offered places in secondary schools on merit. The assumption here is that students who do very well in the Primary School Leaving Examinations (PSLCE) are bound to succeed in their secondary school studies regardless of the quality of learning and teaching in the primary schools from which they come. The Johnson Survey Team elaborated its position on the necessity of offering secondary school places to students on merit:

Competition for admission to secondary schools is bound to be keen ... Selection, therefore becomes a matter of the utmost urgency. Under such circumstances, since the nation cannot educate all, it must make sure it is educating the best-qualified persons. Merit must be the sole standard. (Johnson *et al.*, 1964: 23).

Considered in light of the previously presented recommendation of the Phillips Commission, the excerpt above begs the question of whether a selection instrument can identify the best qualified students to benefit from secondary education, where the quality of primary school graduates is low. The Phillips Commission says it can't. The idea that highly selected students would succeed in secondary education is not peculiar to the Johnson Survey Team. Lewin (1993: 11), for instance, expresses the same idea when he laments that students in Ghana whose performance was very low in the Second International Evaluation of Educational Achievement (IEA) were from 'selective elite schools'. Lewin's argument is that because the students were from a selective elite school, they should have done better. Similarly, Dzama and Osborne (1999: 388) refer to the same idea in writing about highly selected students who perform 'below expectation in science'. Students who are offered places in secondary schools on merit are thus generally expected to do very well in various subjects in national examinations. They are taken to be efficient learners. This chapter sets out to determine whether such students are indeed efficient learners.

### **Reduction of periods allocated to the teaching of science**

After independence in 1964, Malawi contracted UNESCO experts to design a new curriculum for primary education. The experts produced the 1966 Primary School Syllabus, in which rural science was replaced with general science. General science is a combination of physics, chemistry, biology, and some aspects of agriculture and health education. In 1982, however, the Malawi government replaced the 1966 syllabus with a 1982 syllabus. The 1982 syllabus substituted general science with science and health education, in which science and health education were each allocated two periods per week. This means that since 1982, primary school children in Malawi have had two periods of science teaching per week, instead of the usual five periods per week recommended by UNESCO. The reduction of periods was accompanied by removal from the syllabus of all sections relating to practical investigation and discussion of the role of science in agriculture, health and in everyday life (see Ministry of Education, 1966; Ministry of Education and Culture, 1982). DeWitt's (1969: 138–139) astute observation that the basic goal of African leaders in the 1960s and 1970s was 'perpetuation of their personal political power for privileges sake', and that the greatest threat to this power was scientifically educated men and women, rings true to the experiences of Malawi.

It is contended in this chapter that the relative neglect of primary education and the reduction of periods for teaching science are some of the factors that have to be addressed if performance of students is to improve. In the conclusion of the chapter we suggest what teachers could do to alleviate the problem of poor-quality primary education among secondary school students. Before presenting the empirical study, we present a description of primary education to show how the quality of its graduates has remained low.

### **Quality of primary education**

In 1947, Fraser, who was at that time Acting Director of Education, wrote about primary education that was 'grinding round a vicious circle of poorly equipped teachers, running dull schools which turn out a further supply of the same sort of teachers' (Fraser, in Lamba, 1984: 27). Seventeen years later, the Johnson Survey Team concurred with Fraser when it described the primary education system in Malawi as 'a syndrome of inadequacy – inadequate training, deficient teachers, poorly educated pupils' (Johnson *et al.*, 1964: 37). Similarly, the Education Service Review Report of 1988

described primary education as a system under stress. According to the report, schools lacked basic infrastructure and in-service support for teachers (Ministry of Education, 1988). The introduction of free primary education in 1994 raised the enrolment of primary education from 1.9 to 3.2 million (Ministry of Education, Sports and Culture, 2000: 10). This enormous and unplanned increase necessitated employment of 18 000 unqualified teachers. The employment of unqualified teachers led to less effective teaching. Physical conditions in primary schools have hence remained poor. In 1998, 1999 and 2000 the average number of pupils per qualified teacher was 133.7, 118.1 and 122.7, respectively (Kadzamira *et al.*, 2004: 31). In the same years, the average number of pupils per teacher (unqualified teachers included) was 67.4, 63.2 and 63.0, respectively (Kadzamira *et al.*, 2004:31). This suggests that about half of the primary school teachers were unqualified. In addition, there were insufficient desks and chairs to accommodate the increased learner enrollment (Kadzamira *et al.*, 2004: 32).

This brief account of primary education shows that in Malawi students in primary schools learn in poor conditions. The question is can students graduating out of such poor learning conditions develop Martin's (2004) skill and will to learn physical science? These authors think they are unlikely to do so.

### **The empirical study**

This study has benefited from work on learning that was pioneered by William Perry (1988). Perry found that the learning difficulties that students experience spring from their views of knowledge. He also found that the process of schooling may create misconceptions about the nature of learning in students' minds. Perry (1988) studied development of concepts of knowledge by interviewing Harvard undergraduates over their four years of experience in college. He postulated nine positions in the development of students' conceptions of knowledge. Finster (1989) condensed Perry's nine positions into four positions, namely: Dualism, multiplicity, relativism and commitment in relativism. Dualism is the position where students see the world as involving opposites such as right/wrong, good/bad, and we/they (see Finster, 1989: 659). In the multiplicity position, diversity and uncertainty in knowledge are recognised as legitimate features. In the relativistic position students realise that knowledge is contextual and relative. The commitment in relativism position involves recognising the

implication and taking responsibility for the commitment. Perry's (1988) position is that students' beliefs about knowledge and learning affect their approaches to learning and, subsequently, determine their success or failure in learning. Shapiro (2004: 2) concurs with Perry (1988) when he writes that since the Second World War students' 'beliefs and ideas' have been taken to be the 'key in understanding students' learning'. Students' ideas and beliefs about knowledge and learning have been amply investigated in the science education literature.

In 1990, Schommer suggested a re-conceptualisation of personal epistemology as a system of independent beliefs. Schommer (1990) followed Ryan (1984) in using quantitative approaches to measure beliefs about knowledge. Schoenfeld's (1983) suggestion about the importance of incorporating beliefs about learning when studying beliefs about knowledge, found application in the work of Neber and Schommer-Aikins (2002). Other authors, such as Dweck and Legget (1988), provide evidence that students' beliefs about ability to learn affect the learning process. Similarly, students' beliefs about the nature of knowledge and learning influence their approach to learning tasks (Edmondson and Novak, 1993; Clarebout *et al.*, 2001). Beliefs such as learning taking place fast or not at all, ability to learn being fixed at birth, slow learners not being able to succeed in learning, and reading a passage once is enough to understand it, are known to influence students' learning. These beliefs are referred to as dysfunctional beliefs because they inhibit learning among students who hold them. Do secondary school students in Malawi hold these beliefs?

The present study builds on the work of Schommer-Aikins and uses a questionnaire adapted from the literature to survey dysfunctional beliefs about learning and science held by secondary Class 3 students in 15 schools from the three regions of Malawi. The assumption of this study is that students perform poorly in the sciences because they lack knowledge and beliefs about learning that may facilitate success in their learning. It is also assumed that the students lack learning skills. Learning skills are tools that enable students to acquire knowledge and improve their mental competence (Gettinger and Seibert, 2002). Learning strategies, on the other hand, are learning skills integrated and employed by students 'with a purpose in view' (Nisbet and Shucksmith, 1988: 6). Learning strategies therefore involve personal initiative on the part of the students. In-depth interviews were used to tease out learning skills and strategies that students used in learning physical science. The study draws also on

Brooks and Brooks (1993), who maintain that students' failure in school is a reflection of the manner in which they were taught.

### **Rationale and methodology**

The purpose of the study was to find the things secondary Class 3 students in Malawi do on their own to learn physical science. Cheung (2004) identified six aspects of academic self-management: motivation, methods of learning, use of time, physical environment, social environment and performance. Methods of learning among students is the object of this study. The object of study was accessed through a general survey of students' beliefs about learning and in-depth interviews. Items of the survey were drawn from the literature and were pre-tested. The test re-test reliability of the items was 0.81. The questionnaire was validated by one language and two science education experts who advised modification of the questionnaire to include the free response section that asked students to state what they thought was the main cause of underachievement in science education. The interview protocol was also pre-tested and improved as a result of the pre-testing experience. Four students per school were interviewed – two boys and two girls. In some schools, more than four students were interviewed. In some participating schools, group interviews were held with the best four or five physical science students, depending on the time available for the interviews. This chapter presents the results of the questionnaire and interview aspects of the study. Results of the survey are presented before results of the interviews.

### **Results of the survey**

The results indicate that students in Malawi have dysfunctional beliefs about science and science learning, and that they also have poor orientations to science learning. The results are arranged in Tables 1 and 2, which show the mean score and standard deviation for ten items with the lowest mean and ten items with the highest mean. This arrangement of scores is to facilitate identification of the learning characteristics of the students. All items were scored on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

**Table 1: Ten questionnaire items with the lowest mean scores arranged in order of increasing mean score**

<b>Item</b>	<b>n</b>	<b>Mean score</b>	<b>Standard deviation</b>
Good students of physical science do not have to work hard to succeed in the subject	1 286	1.81	1.13
One's ability to learn physical science is fixed at birth	1 294	2.06	1.99
Scientists are born with ability to do science	1 298	2.36	1.37
Only gifted students can succeed in learning difficult tasks in physical science	1 278	2.40	1.24
If a person tries very hard to understand a problem they will most likely end up being confused	1 282	2.41	1.24
Working hard on difficult problems in physical science pays off only for good students	1 291	2.79	1.41
You will get confused if you try to combine new science ideas with your own ideas	1 296	2.87	1.62
Those who fail examinations are lazy	1 288	2.88	1.48
The best way to learn science is to memorise facts and principles of science	1 286	2.89	1.47

**Table 2: Ten questionnaire items with the highest mean scores arranged in order of decreasing mean score**

<b>Item</b>	<b>n</b>	<b>Mean</b>	<b>Standard deviation</b>
Scientists can get to the truth if they keep trying	1 292	4.14	1.02
I do sufficient work to succeed in learning physical science	1 282	3.98	1.02
Every student can succeed in learning physical science	1 279	3.90	1.15
I am certain that I understand ideas taught in physical science	1 286	3.81	1.13
I can do the exercises in the physical science textbook	1 296	3.80	1.14

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When learning physical science I look for the facts given by the teacher	1 292	3.80	1.12
I can succeed in physical science studies at university level	1 289	3.79	1.32
My work in physical science is sufficiently challenging to enable me to learn it	1 288	3.66	1.24
Only students who have ability to learn physical science can succeed in the subject	1 289	3.62	1.42
Scientific knowledge is an accurate description of reality	1 266	3.58	1.16

### **Results of the interviews**

Analysis of interview transcripts indicates a lack of latitude in students' learning conceptions and practices of learning. To many students, learning physical science is a matter of reading or listening carefully to what their teacher says; as Chancy maintains in the excerpt below:

In: What do you do to learn physical science?

Chancy: Actually its just a matter of paying attention to the teacher what he or she is saying to the students.

In: After classes do you do anything?

Chancy: After classes, that is when we have knocked off?

In: Yes, after classes, after the teacher has taught you and you go back, what do you do?

Chancy: As I have already said, the students are categorised into two groups. There are others who know what they are here for and those people who have to do the work again and correct their mistakes.

In: How do they do the work again?

Chancy: They do it again by asking those people who have done well and may be having an assistant, a helper who could be asked: How did you do this? How did you tackle this?

According to the excerpt above, some students do not follow up their lessons. This is contrary to Hotano's statement (in Heller, 1993: 150) that: 'For science and mathematics, practice is done outside school'. For some students, learning is getting information from the teacher; as Miliasi explains:

In: How do you learn physical science?

Miliasi: Physical science actually I learn through my friends. When it is time for when my teacher is teaching I do get what he is trying to say but actually it is through my friends after classes I go and ask my friends so that they tell me one by one what the teacher was saying.

In the excerpt above Miliasi takes learning to other students telling him what the teacher said in class. This reduction of learning to merely being told – i.e. listening to teachers or other students – is a recurring theme in the interview transcripts. Talumba expresses the same idea in the context of discussion groups:

In: How do you learn physical science on your own after classes?

Talumba: After being taught by the teacher with some other, maybe, chemicals or organic compounds after going to the hostels we do practice tests taught by the teacher in order to know more about those things.

In: How do you do this?

Talumba: We are organised into groups there at the hostel. We are in groups of three or five girls to be teaching one another. Those who have been taught by the teacher may be somebody did not understand what the teacher had said, others understood so those who understood tend to the others.

Christy was even more explicit in her reduction of learning to receiving information, as the excerpt below indicates:

In: What do you do to learn physical science?

Christy: Firstly I get the information from the teacher, thereafter I visit my friends so that I can learn more information, then I do also read my books, the Physical Science books which we were given.

What appears odd in these excerpts is the absence of reference to problem solving, visualisation, elaboration, note making, practising drawing of diagrams, drawing Venn diagrams to show relationships between concepts

or developing mnemonics. Students' learning activities appear to be limited to discussion in small groups, reading and listening to students who understood the teacher.

### **Discussion and implications**

The survey results indicate the presence of a strong desirability bias among the students. All the items in the questionnaire that started with 'I' fall in the ten items with the largest mean score. This finding confirms the presence of a strong desirability bias that Sjoberg and Schreiner (2005) found in the responses of Malawian students to the Relevance of Science Education (ROSE) questionnaire. The questionnaire data therefore has to be interpreted with caution.

The students may have heard that memorising things without understanding them is a poor learning strategy. They consequently rejected the questionnaire item that reduces learning to memorising. Their admission that 'they look for facts given by the teacher' when learning science contrasts sharply with their rejection of memorisation as a way of learning science. Looking for facts given by the teacher amounts to resorting to memorisation as a learning strategy. The concept of science is of positivistic formulation. Positivistic statements of the nature of science fall in the ten items with the highest mean. A comparison of the responses of Malawian students and those of gifted high school students in America, reported in Neber and Schommer-Aikins (2002), is presented in the next paragraph.

In their study of self-regulated learning among highly gifted students, Neber and Schommer-Aikins (2004) administered similar items to those used in this study. A comparison of the performance on selected items of Neber and Schommer-Aikins' highly selected students and secondary Class 3 students in Malawi is provided below.

**Table 3: Performance of gifted high school students in the USA and secondary Class 3 students in conventional schools in Malawi**

Variable	Gifted USA high school students		Malawi students	
	M	SD	M	SD
Innate ability to learn	2.47	0.63	3.15	1.52
Learning is quick	1.76	0.52	3.39	1.37

Table 3 indicates that beliefs about learning among Malawi students differ from those of their USA contemporaries. Beliefs about speed in learning and innate ability to learn score high among Malawi students and low among American students. Such beliefs inhibit learning when students see themselves as slow learners or as having no ability to learn successfully. Powell (1990), writing from the perspective of African Americans, points out that these beliefs seem to suggest that there is some flaw in the student and are most damaging to success in learning.

Given that the students were highly selected, their performance on the questionnaire is disappointing. The questionnaire has four items relating to learning by memorising things. Except for the item that has the word memorise in it, the students do not seem to have perceived these other items as having anything to do with memorisation. They seem to perceive activities such as looking for facts given by the teacher and learning teachers' notes by heart as having nothing to do with memorising learning strategy.

The students scored high in the items we would expect them to score low in, and vice versa. Although their performance in national examinations is poor, Table 2 suggests that they see themselves as students who are capable of doing very well in science. Cokley (2003) reports a similar phenomenon among African Americans. According to Cokley, African Americans maintain a 'high academic self-concept in spite of lower academic achievement' (2003: 530). Similarly, the students in Malawi seem to see themselves as highly capable students, even though examination results suggest otherwise.

The interviews revealed that students in secondary schools in Malawi do not know what they can do to enhance their learning. The only learning skills they think about are reading and listening and discussing in groups. This means that the students completed primary education and two years of secondary education without learning any learning skills other than reading and listening and discussing in groups. The authors believe that this reflects the generally poor learning conditions that prevail in primary schools and in some junior secondary schools.

## **Conclusion**

The purpose of this study was to determine the learning skills that are used by secondary school students in Malawi when learning physical science. It has been presented that because of the poor learning environments

that have been perpetuated by the policies pursued in the primary sector, students are likely to be deficient in those learning skills that would facilitate success in learning science at a secondary level. The results support this argument. To most students in Malawi, learning science is either listening or reading or discussing in small groups. Teachers in secondary schools should be advised to either teach students learning skills explicitly or to create richly furnished, challenging learning contexts in which students can be given opportunities to evaluate their work and take learning risks. In view of the generally impoverished teaching and learning environments that prevail in the country's secondary schools, the former recommendation should be adopted.

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# *11. The Rationale for Science Education, Curriculum Change and Reform in Sub-Saharan Africa: The Case of Zimbabwe*

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## **Abstract**

This article debates the rationales for science education and curriculum change and reform in Sub-Saharan Africa. Zimbabwe is used as a case to illustrate and exemplify the issues raised in the debate. It is argued that investment in science education, increasing access to science education, and science education curriculum change and reform can only contribute to a country's socio-economic development if the political and economic environment is conducive. The article first presents a brief overview of secondary school science curriculum change and reform in Zimbabwe since independence in 1980. It then tackles the issue of science education for socio-economic development as a rationale for science education. In that effort questions are raised about what constitutes relevant science education curricula for Sub-Saharan countries. It is suggested that for Sub-Saharan countries, the development of human resource needs should not only be the major reason for offering secondary school science, but also the major determinant of the nature of curricula. This has implications for curriculum change and reform. The wisdom of 'science education for scientific literacy' is questioned. Sub-Saharan countries are advised to be wary of some of the curriculum reform agendas, which are more relevant to developed countries than developing countries.

## **Introduction**

For most Sub-Saharan countries, political independence ushered in a new era of hope and expectation. It was envisaged that independence would result in socio-economic/human development. For the purposes of the discussion in this chapter, we conceive human development to be progress in terms of the material well-being of citizens and the eradication of poverty, disease, ignorance and illiteracy. Our understanding of development encompasses the need for progress in empowering people and ensuring that they have equal opportunity to resources and can fully participate in the development process. While we subscribe to this notion of development, we also acknowledge that traditional ways of describing a country's level of socio-economic development such as the Gross Domestic Product (GDP) can play important roles in illuminating and understanding the totality of the process of development.

Much of the hope and expectation mentioned in the preceding paragraph hinged upon the assumption and conviction that investment in education in general, and science education in particular, facilitates desirable socio-economic transformation. Globally, an education in science is seen as important for: development of a labour force or human resources, empowerment of society's citizens in decision-making/democratic citizenry (e.g. participation in debating socio-scientific issues), producing citizens who can adapt to an increasingly complex scientific and technological world, and significant in addressing issues of poverty and sustainable development (Bingle and Gaskell, 1994; Longbottom and Butler, 1999; Hurd, 1998; Khan 1998; Kyle, 1999; Laugksch, 2000; Laugksch and Spargo, 1996; Kolstø, 2001; Makhurane and Sjøberg, 1998; UNESCO, 1990). For many developing countries (including Sub-Saharan countries) these noble aspirations have become justifiable rationales necessitating not only a need to increase access to science education for the majority of citizens, but also to change and reform science education policies, practices and curricula in order to foster the aspirations of the envisaged socio-economic order. In Zimbabwe, the advent of political independence (in 1980, from British rule) saw a wave of science education curriculum change, reform and innovation.

Within the context of developing countries, this chapter debates the rationale for science education in general, and curriculum change and reform in particular. The chapter raises some pertinent issues which are relevant to Sub-Saharan countries in general. The Zimbabwean experience

is used to illustrate some of the points raised in the debate. It is argued that investment in science education, increasing access to science education and science education curriculum change and reform, can only translate into socio-economic benefit if the political and economic environment is conducive. Furthermore, it is the authors' contention that for Zimbabwe and the Sub-Saharan region, much of so-called curriculum change and reform has been nothing but 'wholesome enculturation' of curriculum fashions and trends developed in the West. While it is true to say that science education curriculum change and reform must be sensitive to global shifts and trends, there is also a need for Sub-Saharan countries to be wary of some of the curriculum reform agendas, which in the authors' analysis are more relevant to industrialised countries than the realities of Africa. We believe that the issues we raise in this debate have far-reaching implications for the content of secondary school science education curricula in developing countries.

## **Overview of Zimbabwe secondary school science curriculum change and reform**

### **Expansion of education and the ZIMSCI project**

At independence in 1980, the ZANU-PF government embarked on a massive expansion of the education system (see Table 1). The slogan then was 'education for all citizens'. From a political and ideological perspective, it was necessary to increase the citizens' access to education as a way of addressing the imbalances created by decades of racial segregation and colonialism. The ZANU-PF government adopted a scientific socialism based on Marxist-Leninist principles as the guiding philosophy for the country's socio-economic transformation. 'Growth with equity' was adopted as the principle to drive the redress in the education system and other sectors (such as, health, agriculture and industry) (Kanyongo, 2005). The massive expansion of the education system saw the number of primary and secondary schools increasing dramatically between 1980 and 1989 (Ministry of Education, Sport and Culture, 2001). By 1989, the number of primary schools had increased to from 2 400 (in 1980) to 4 500. The number of secondary schools increased to 1 500 from 177 (in 1980). Inevitably, this massive expansion in the education system also meant increased access to science education. At the same time the amount of money government allocated to education increased to 22.6% of total

government recurrent expenditure, compared to 4.4% at independence (Kanyongo, 2005).

**Table 1: Expansion of education in Zimbabwe, 1980 to 2004**

	<b>Number 1980</b>	<b>Number 2004</b>	<b>Enrolment 1980</b>	<b>Enrolment 2004</b>
Primary schools	2 400	5 007	647 761	2 400 000
Secondary schools	192	1 680	66 000	1 500 000
Technical colleges	2	10	2 000	16 241
Teachers' colleges*	8	15	2 829	18 000
Universities	1	12	1 000	54 000

*\* Compiled from Kanyongo (2005) and Zimbabwe Ministry of Foreign Affairs, Zimbabwe Ministry of Education websites*

In the early 1980s most of the policy statements issued by the Ministry of Education, Sport and Culture parroted Karl Marx's 'polytechnic education', whose objective was to integrate mental and manual work, and produce 'wholesome individuals' who valued the dignity of manual labour and could easily be absorbed by the labour market. It was important to align the curriculum and instruction to the economic and social reality of Zimbabwe. The new polytechnic education placed great emphasis on science and technology education. So strong was the emphasis on science and technology education that the Curriculum Development Unit (CDU) of the Ministry of Education, Sport and Culture was officially mandated to ensure that developed curricula would have a 'strong scientific and technological bias' as 'part of government strategy for development'. In Zimbabwe curriculum development is centralised.

To ensure that all secondary school students would have access to science education, the government adopted and implemented the Zimbabwe Secondary Schools Science project (ZIMSCI project) in 1981. A science education course for the Junior Certificate level was developed using cheap materials that were mainly made locally – namely, the ZIMSCI kit. With this project, students were able to learn science and perform simple science experiments even in poor rural secondary schools, called Upper-tops. Programmed teacher and students guides made it possible for students to learn science; even under the guidance of untrained teachers and without a formal science laboratory. The ZIMSCI project was expanded

to cover the teaching of science at Ordinary Level (O-Level). Although initially successful, the ZIMSCI project eventually ran into problems as schools found it difficult to replace or repair ZIMSCI kit materials. By the mid-1990s most of the kits supplied during the early 1980s were virtually empty and schools were struggling to ensure that students had access to science textbooks and other learning materials. In most schools, teacher chalk and talk remained the most prevalent method of teaching science.

### **Core and extended science: The resistance**

The politically and ideologically driven polytechnic education which the ZANU-PF government envisaged necessitated a shift in curriculum orientation and content from purely academic to utilitarian. A new O-Level science curriculum was developed and introduced by 1988. The new curriculum had a Core Science syllabus, which was compulsory for all students but was specifically meant to cater for 80% of the O-Level students who would not proceed to study science at Advanced Level (A-Level). An Extended Science syllabus was available for those students (20%) who could go on to study science at A-Level. In most rural schools the depleted ZIMSCI materials were the only resources available for teaching and learning. However, some defiant mission schools continued to offer Cambridge science syllabi alongside the new syllabi. The significance of this will become apparent shortly.

The content of the Core Science syllabus was organised around themes of: agriculture, the community, industry, energy uses and mechanical systems. School Certificate examinations for both Core and Extended Science were set and administered by the Cambridge Local Examination Board. It was only in 1994 that the government – through the Zimbabwe School Examinations Council, ACT No. 17 – established the Zimbabwe Schools Examination Council (ZIMSEC) for the purpose of conducting school examinations from primary school to Advanced Level. By 1990, however, the setting and marking of O-Level examinations was already being done locally, with accreditation from the University of Cambridge Local Examination Syndicate (UCLES). Localisation of A-Level examinations started in the early 1990s and was completed by the beginning of 2000.

Naturally, examination through the UCLES was to have unmistakable imprints on the nature and content of the science curricula developed in post-colonial Zimbabwe. For example, although the textbooks that were recommended by the Ministry of Education to cover the content of Core

Science syllabus (such as *Science for Zimbabwe* and *Focus on Science Book III*) attempted to make the science relevant to Zimbabwe through the use of local illustrations, the essence of the Core Science curriculum was in fact a microcosm of the Science, Technology and Society (STS) movement's agenda. Understandably, the science curriculum was developed at a time when the agenda of the STS movement was gathering momentum in both Europe and the USA. One of the major aims of an STS-oriented curriculum is to develop student understanding and appreciation of the interactions among science, technology and society. The STS curriculum content is organised around important issues such as HIV/AIDS, acid rain, global warming, waste management, water quality and resources, and sustainable use of the environment and its resources (Hurd, 1998). It was not by coincidence that the Zimbabwe O-Level Core Science curriculum was also organised around themes such as science in the community and science in society. In fact, any lingering doubts about the hegemonic influence of the STS movement on the nature of the Zimbabwe Core Science curriculum disappear when one examines aims and objectives of the syllabus, which broadly seek to capture the agenda of the STS movement.

For a variety of reasons, such as international recognition of School Certificates, it was also important that the newly developed syllabi be seen to be matching educational standards in the former colonial power. Commenting on the new A-Level syllabi, ZIMSEC proudly declares:

The syllabuses were evaluated by the National Academic Recognition Information Centre (NARIC) to establish their comparability with the GCE [Cambridge] standard. I am happy to report that most of the subjects that we offer at this level are comparable to the GCE standard; a copy of the NARIC report is enclosed for your perusal. (<http://www.zimsec.co.zw/>)

By the beginning of the 1990s, therefore, the Zimbabwe O-Level science curriculum was: a former colonial power prototype, largely STS-oriented in content, examination-based, mainly academic, and out of tandem with the utilitarian aims and visions of the propounded polytechnic education ideology – namely, self-reliance, entrepreneurship, and responsible and productive citizenry. Cosmetic changes were made to the A-Level subjects' science syllabi, but in essence they remained the same UCLES syllabi that had been adopted in 1980.

Some dissenting voices started to raise alarm about the quality of science education being offered at O-Level. Many A-Level teachers (in biology, chemistry and physics) complained that the Extended Science done at O-Level did not adequately prepare students to study A-Level Sciences. The result was that some students (especially in well-established mission schools) were disadvantaged when it came to choosing a career in science at A-Level; as many mission schools refused to offer science at A-Level to those students who had done Extended Science. Moreover, there was a general belief that the so-called Zimbabwe Science offered in the Core Science syllabus was some form of dilute and inferior science, different from the 'actual science' offered during colonial times. There was an outcry that standards were going down. Meanwhile, in the schools, pedagogical practices remained largely teacher-centred with increased cost and shortage of science teaching materials providing teachers with a ready excuse for their practices (Vhurumuku, 1992).

The misgivings described about the O-Level Core and Extended syllabi were major contributors to the more established mission schools offering the traditional physical science and biology over and above the officially recommended science syllabi. This meant that some students did four science subjects. A few schools were also offering physics, chemistry and biology as single subjects at O-Level. In spite of thinly veiled threats from the Ministry of Education, Sports and Culture, the schools continued to despise Core and Extended Science. Most of the poor rural schools, however, continued to offer the recommended syllabi.

### **Back to colonial roots: Integrated science, physical science and biology**

In the early 1990s, the offering of physical science and biology at O-Level had expanded beyond former mission schools. In 1996, the government, through the CDU and ZIMSEC, introduced an O-Level Integrated Science Syllabus 5006 to replace the Core Science syllabus. Essentially, the change from Core Science to Integrated Science proved to be in name only, as the themes and subject matter of the Core syllabus were retained. In response to concerns expressed about the quality of the science education that was being offered, syllabus 5006 also assumed hybrid features reminiscent of the UCLES' General Science and Combined Science syllabi, which were on offer to 'less gifted' black students during colonial times. While sciences remain compulsory at O-Level, students are no longer compelled to study integrated science, and can study a combination of two or more science

subjects as in physical science and biology, or chemistry and biology. The following science subjects are currently on offer at O-Level in Zimbabwe's schools: biology, chemistry, physics, human and social biology, integrated science, physical science (chemistry, physics), science (physics, biology), and science (chemistry, biology).

For all these subjects, aims and objectives, content, and assessment framework of the syllabus are basically the same as current UCLES syllabi in the UK. What has been localised is the school examination system. The localisation has been driven by economic expedience and is only justifiable on the basis of saving the country much needed foreign currency, which ZIMSEC would have to pay to the UCLES.

Thus, after almost three decades of independence, the Zimbabwe school science curriculum is still far from being home-grown and 'relevant' to the country's socio-economic realities. A national report on education and the development of education (Ministries of Education, Sports and Culture and Higher Education, 2004) acknowledges that quality and relevance are still major problems in the education sector. This is so despite the Presidential Commission of Inquiry into Education (Nzirasanga, 1999) whose report recommended radical changes to the school curriculum. The report mourns the lack of provision for life skills in secondary school education and blames this for the high rate of unemployment. One shocking finding of the inquiry was that the quality of education was deteriorating, with high levels of illiteracy among the ranks of secondary school students – some Form 2 and Form 4 students could hardly write their names, let alone be 'scientifically literate'. Government commitment to science education curriculum change and reform has remained largely rhetorical with action in the direction of implementation being lethargic. This is unlike the changes which have been implemented to, for example, the O-Level history syllabus, which now contains more than an overdose of ZANU-PF synthesised liberation war history, propaganda and patriotic nationalism. The objectives of such a curriculum are very clear: to instil a revolutionary spirit, counter imperialist- and opposition-driven propaganda, develop a mature sense of patriotism, and raise awareness about the importance of the country's sovereignty.

Sadly, over the past seven years, Zimbabwe has sunk deep into political and economic problems, isolating itself from the international community, and is under an increasingly anti-West, hostile and paranoid government whose project of authoritarianism (Raftopolous, 2003) has unleashed an

unhealthy politicisation of the curriculum development process. This scenario has made it difficult for science education curriculum change and reform to integrate ideas which appear to have emanated from the West. For example, while science education curricula in almost all SADC countries are moving in the direction of incorporating explicit teaching about the nature of science (NOS) and indigenous knowledge (IK), there is no evidence in Zimbabwe at the moment that this regional and indeed global trend in curriculum reform might be accommodated. This reality is a sad contradiction because the current science curricula are still inherently based on colonial prototypes.

### **The rationale for science education in Sub-Saharan Africa**

Our discussion to this point has highlighted how Zimbabwe's post-colonial secondary school science education curricula change and how reform has remained largely cosmetic. It is from this perspective that we now interrogate the rationale for science education in Sub-Saharan Africa.

According to DeBoer (1991) the questions 'What is the rationale for teaching science?' and 'What should be the content of science education curricula?' have been part of debates in science education since the mid-Nineteenth Century. Today, as independent African nations grapple with the challenges of how science education can contribute to development, these same questions must of necessity be tackled. As far as the first of these questions is concerned, the purpose of offering science education can be encapsulated into two broad but inter-related rationales, namely: science education for socio-economic development and science education for scientific literacy. In this chapter we debate some of the issues surrounding science education for socio-economic development.

#### **Science education for socio-economic development**

It has already been mentioned that, globally, a link has been assumed to exist between science education and socio-economic development. In all Sub-Saharan countries, investment in science education is seen as a sort of panacea to problems of poverty, development, sustainability, participatory democracy and good health. Enos (1995) estimated that for Sub-Saharan countries (for example, Uganda, Tanzania, Ghana and Kenya) total expenditure (as a proportion of the GDP) in the pursuit of science and technology increased substantially between the years 1979 and 1992. This total expenditure includes: money spent on teaching and learning

in educational institutions (the largest chunk goes to paying salaries – for example, 90% for Zimbabwe), expenditure on research and development activities, and training and technical services. To a large extent, the pattern observed by Enos continues to be a feature in many Sub-Saharan countries. In some instances, increased expenditure on science education has been supported by inflow of financial assistance as a result of International Monetary Fund (IMF) and World Bank structural adjustment programmes; NGO-funded projects and North–South co-operation agreements.

According to Khan (1998), much debate has hinged upon the advocacy that investment in science and technology education will result in economic growth and revival. It has been argued that funding science education and scientific research could produce skilled human-resource and technological innovation and improvement, which are fundamental in lifting economies and encouraging development. Much emphasis was placed on the importance of science and technology for development and the development of policies and curricula that were germane to the context and reality of Africa. It was within this spirit that the government of Zimbabwe launched a Science and Technology Policy on 5 June 2002. The policy aims to promote national scientific and technological self-reliance through, among other strategies, popularising science and technology and promoting research and development.

### **Zimbabwe: Some human development indicators and the decade of progress**

Given the above background, the questions to answer are: Has investment and expansion of science education resulted in the expected development gains in Zimbabwe? And, has the science education curriculum change and reform outlined above had an impact on socio-economic development? Through such an interrogation, it is possible to arrive at a conclusion about the ‘justifiability’ of science education for socio-economic development as a rationale, and the wisdom of wholesale change and reform of science education curricula across the sub-continent.

While we attempt to answer these questions we remain mindful of what others before us (Volmink, 1998; Olson and Krugly-Smolka, 1998) have noted – that the contribution of science education to socio-economic development is difficult to locate, concretise and clearly elucidate. This is so because the link between science education and development is complex and multi-directional. Furthermore, as the United Nations

Economic Commission for Africa (2000) has observed, explicating that contribution and establishing a valid linkage between provision of science education and human development is in itself fraught with theoretical and methodological pitfalls. Nevertheless, our contention is that however crude the current measures of the contribution of science to development are; they still provide useful indicators for the meaningful evaluation of that contribution.

We believe that the impact of investment and expansion in school science education on socio-economic development can be estimated by considering such indicators as: professionals and other workers in science- and technology-related careers (such as, engineers, doctors and science teachers) as well as the gender equity in such professions); research and development activities including technological innovation; and levels of literacy (mainly scientific technological literacy). Our reference to these indicators is based on the assumption that it is relatively less tedious to relate them to both the provision of science education and science education curricula. While the indicators are far from being adequate and all-inclusive, they can be qualitatively integrated into such other primary measures as life expectancy, GDP, GDP per capita, unemployment and poverty levels (Human Poverty Index) to produce a fairly reasonable picture of the state of socio-economic development for any given country.

Table 2 presents a crude picture of the trend of human development in Zimbabwe since independence. The table captures some of the indicators referred to in the preceding paragraph.

As the overall HDI shows, Zimbabwe made some progress during its first decade of independence. A considerable portion of this progress can be attributed to the country's achievements in science education. By the close of the decade, the investment and massive expansion of education, which the government had embarked on in 1980, was beginning to bear fruit and gains were made on such fronts as: increased participation of women in science education; female enrolment in science and science-related disciplines at universities rose from below 10% of total enrolment in 1980 to about 33% in 1990; reduction of the number of unqualified science teachers (according to Ministry of Education only 7.4% of the teachers were unqualified in the year 2000); and an increase in the number of trained medical personnel (doctors, nurses, pharmacists, pathologists, etc.). By 1998, Zimbabwe was producing 80 doctors and 300 nurses per annum, a healthy figure given the size of the population and compared to many African countries.

**Table 2: Some Human Development Indicators<sup>1</sup> for Zimbabwe (1980 to 2005)\***

Development indicator	Year					
	1980	1985	1990	1995	2000	2005
Female participation in secondary education (% of total enrolment)	43.30	40.40	43.40	45.60	46.90	–
Public expenditure on secondary education (% of per capita GDP)	–	32.70	28.60	33.30	20.10	7.70
Adult literacy level (% age 15 and above)	–	75.80	80.70	84.70	89.30	89.30
Life expectancy	56.00	58.00	61.00	41.00	35.40	32.60
Unemployment (%)	–	–	–	35.00	50.00	80.00
Economic growth (%)	2.70	4.00	4.00	3.00	–11.40	–8.50
Inflation (% annual)	–	–	–	120.00	600.00	400.00
GDP per capita (U.S.\$)	–	–	–	2 515.00	1 726.00	259.00
Human Poverty Index (% below poverty datum line < US\$2 per day)	–	–	36.00	36.00	70.00	83.00
HDI	0.57	0.63	0.62	0.57	0.49	0.51
World HDI rank	117.00	117.00	79.00	121.00	133.00	151.00

\* Figures quoted are estimates compiled from United Nations Development Programme (UNDP) Reports from 1980 to 2007 available at [http://hdrstats.undp.org/countries/data\\_sheets/cty\\_ds\\_ZWE.html](http://hdrstats.undp.org/countries/data_sheets/cty_ds_ZWE.html) [accessed 21 March 2008]

Overall, Zimbabwe was doing well on the education front and the secondary school system was feeding tertiary institutions with enough students for the country to train and meet its human-resource needs in fields such as engineering, technology, agriculture and health. Adequate human resources in these areas is a prerequisite for delivery of social services and

an improvement in the standard of living of the people. While not much was happening in technological innovation and scientific discovery, both secondary school and tertiary science education were doing enough to ensure that there was a constant supply of skilled and professional labour to keep the economy running. This was the case irrespective of the nature of the school science education curriculum, which primarily aimed to channel students into white-collar labour instead of producing self-reliant, self-employed citizens; as envisaged at independence and by the government's five-year development plans, which came into effect in 1991 in line with the adoption of the World Bank and IMF Economic Structural Adjustment Programme (ESAP).

### **The rationale of science education and curriculum relevance**

It might be argued that the various science subjects offered in Zimbabwe's secondary schools, including integrated science, are elitist since the curricula are designed to channel students into white-collar professions. Such curricula, however, remain justifiable in so far as they serve the interests of the existing economy; to the extent that Zimbabwe's current secondary school science curricula remain relevant and based on a justifiable rationale – they provide human resources for the economy. In the Marxist sense, it is the economic base that determines the nature and form of components of superstructures such as education; and this includes the content of school science curricula. Issues of whether or not science curricula are relevant to a country's socio-economic or human development agendas are difficult to extricate from the realities of economic, scientific and technological dependence in which most if not all Sub-Saharan countries are submerged. It makes sense to say that for as long as the survival of an African county's economy depends on the science, technology and innovation from developed countries, then school science curricula designed to maintain and sustain that dependence are justifiable. This is not to say dependence and subjugation are justifiable; not at all.

To the contrary, some would have it that science education curricula change and reform that seek to bring about relevance are in the long run the *sin qua non* of scientific advances and technological adaptations and innovations that can lift economies and break the shackles of dependence. A salient feature in global development is the apparent association between the level of socio-economic development and a country's ability

and capacity to: generate new technologies, adapt existing technologies to suit local conditions, discover scientific truths, and invent new products (Lewin, 2000). In this regard, it is argued that the kind of school science education curricula offered must prepare young people to contribute to scientific and technological capacity building. According to Lewin (2000), this necessitates a departure from orthodox curricula practices that emphasise discovery and mastery of the subject matter, to strategies that promote development of scientific knowledge related to the poor to ensure development of diagnostic and maintenance skills and social application and utilisation of technology.

Whether or not such curriculum change and reform can contribute to and eventuate in socio-economic transformation remains contentious. Three issues surround the contestation. First, although links between science education and economic development are apparent (for example, having more skilled persons in science and technology and more levels of socio-economic development), it has not been established that advances and changes in science education necessarily lead to socio-economic development (Olson and Krugly-Smolka, 1998). The converse could actually be true – that socio-economically developed nations have been able to support science education advancement, curriculum change and innovation because their economies can afford it. Investment in science education and curriculum change and reform do not necessarily lead to the anticipated results (Fabiano, 1998).

Second, that investment in science education, curriculum change and reform can translate into socio-economic development is contentious because there are other factors in the development equation. Volmink (1998) lists an isolated, stable policy environment, a competent workforce and scientific literacy as other conditions for socio-economic development. To this list could be added contributions from agriculture, mining, industry and good democratic governance. Thus, the role of science education in socio-economic development cannot easily be factored out. How exactly science education contributes to human development is not well understood.

The third issue surrounding science education for socio-economic development is the assertion that investment in science education will culminate in the end product of skilled human resources in science and technology fields which can drive industrial growth and development. As the case of Zimbabwe clearly illustrates, the production of a skilled

workforce and researchers are in themselves no guarantors of socio-economic development. Zimbabwe, which produces a highly skilled workforce, continues to languish in poverty, unemployment and disease. The problem is exacerbated by developed nations who, through baits of financial reward, import trained researchers from developing nations.

In the case of Zimbabwe, it is difficult to fully evaluate the relevance of post-independence school science curricula, since up to the time when the country descended into economic malaise and political chaos<sup>2</sup> existing curricula appear to have been serving the country well in terms of production of the requisite human resources. As we will reiterate in the next section, the achievements in science education, which the country had gained during the first ten years of independence, were eroded and negated by the chaos, turmoil, and unstable politico-economic environment that ensued in the years after 1997. This appears to give substance to the argument that investment in science education and relevance of curricula alone are not enough to guarantee socio-economic development.

### **Zimbabwe: Economic ruin, science education and the brain drain**

Inevitably, the ruinous and suicidal political and economic project which the state embarked on after 1997 was to have far-reaching and dire effects on science education and the stability of the country's skills and professional base. The *Zimbabwe Independent* had this to say about the effect of the economic ruin:

Zimbabwe is losing thousands of talented professionals crucial to its future. President Robert Mugabe's reckless policies are sending thousands of 'born-frees' – the black elite educated after the beginning of majority rule in 1980 – into exile, principally in Britain. The black brain drain – drawing professionals in their twenties to Britain, the United States, South Africa and Australia – is far more serious for Zimbabwe than the widely reported exodus of white farmers,<sup>3</sup> say economists. (*Zimbabwe Independent*, 17 December 2000)

Zimbabwe's *Financial Gazette* concurs:

**A NEW report on staffing levels within Zimbabwe's crumbling healthcare system paints a dire picture of the impact of the brain drain, with vacancy rates for crucial skills in hospitals as high as 70 percent.** More than 3 500 nurses and 969 doctors had left government health institutions by September 2007 after the health professionals intensified their hunt for better opportunities in the region and abroad, a report prepared by the Nurses Council of Zimbabwe (NCZ) says. Statistics in the report show there were 3 502 vacancies for nurses and 969 vacant posts for doctors at the end of last year. (*Financial Gazette*, 20 March 2008).

The massive exodus<sup>4</sup> of skilled human resources continues to seriously affect production and service in all sectors of the economy, compounding the misery brought about by decreased agricultural productivity. Ironically, unemployment levels are very high for the unskilled labour market. While all sectors suffer from the effect of the brain drain, it is the health and education sectors that have been hardest hit. Over the past ten years, Zimbabwe has lost more than 1 000 doctors, at least 20 000 nurses, 500 pharmacists and scores of other health workers. A 2003 Ministry of Health report revealed that of the 1 530 doctors needed in state hospitals, only 687 posts were filled (by the end of 2004 this figure had dropped to 350). Only 6 940 nurses out of a required 11 640 were available in hospitals. This situation has since worsened. The critical shortage of essential staff together with an inadequate supply of drugs and materials, has led to the collapse of the health delivery system (one political commentator said the system itself is under intensive care) in a situation where the HIV/AIDS pandemic is already playing havoc on people's standards of living.

The same can be said of the education sector where the brain drain has compromised the quality of science education offered in secondary schools and tertiary institutions. Institutions of tertiary and higher education (especially universities) are currently faced with a critical shortage of teaching staff, with vacancy rates in departments offering science and science-related disciplines averaging between 50% and 90%. While the supply of qualified secondary school science teachers<sup>5</sup> is still relatively not as critical as in higher education, a Ministry of Education Report (Ministry of Education, Sports and Culture, 2004) identifies the

shortage of qualified teachers as a problem hampering the delivery of quality education, especially in rural schools. It blames the brain drain for worsening the teacher shortage. In 2007 the Zimbabwe Progressive Teachers' Union reported that in 2006 more than 25 000 teachers had left the country for 'greener pastures'.

The greatest threats to the quality of science education delivered in Zimbabwe's secondary schools, however, have been: the shortage of material resources to support teaching and learning, low teacher morale, corruption, embarrassing blunders and inefficiency in the examination delivery system under ZIMSEC. Over the past three years economic ruin and increasing poverty have contributed to declining enrolment in both primary and secondary schools.

According to Raftopoulos (2003), Zimbabwe's problems, including those in education, have a link to the ZANU-PF government's project of authoritarianism, political turmoil and economic ruin. This project has thrived on government mismanagement, institutionalisation of corruption, and ZANU-PF's politics of patronage. Some people (for example, Ismi, 2004) are, however, of the view that the root of Zimbabwe's problems is not just the ruinous project of the state; but is also located in the Structural Adjustment Programme (SAP) which the government was forced to adopt in 1991. This led to decreased economic production and introduced a plethora of problems (unemployment, school dropouts, etc.), all adding up to entrench poverty. Robert Mugabe and ZANU-PF spin-doctors and propagandists maintain that Zimbabwe's state of economic ruin is not the result of mismanagement and corruption, but is instead a direct consequence of sanctions imposed on the country by the USA, the UK and their imperialist allies. They allege that sanctions have been imposed on the country as punishment for taking away land from white commercial farmers and distributing it to landless blacks in order to redress colonial legacy imbalances.

Whichever way one looks at it, the reality is that the gains that Zimbabwe had made through investment in science education and expansion of the education system appear to have been eroded by the emergence of an unfriendly political and economic environment.

### **Some concluding remarks**

For Zimbabwe, expanding science education, without drastically overhauling curricula, appears to have contributed positively to socio-

economic development – at least for the first decade of independence. It might not be necessary for Sub-Saharan countries to make major changes to science education curricula without careful consideration of whether or not the existing curricula are not achieving the goals and functions for which they were created. Current waves of curriculum change and reform in developed countries are driven by such agendas as: making science more interesting to learners (and this is not a major problem in Sub-Saharan Africa); promoting the scientific literacy of citizens including an understanding of the nature of science; and such subtleties and trivialities as improving a country's rank on a ladder of learner achievement in science. It is important for poor countries to reflect on their own realities before 'sheepishly' taking aboard some curriculum reform agendas which only succeed in straining financial resources and do little to eventually lift economies.

Perhaps for countries such as Zimbabwe it is far more important to have curricula that promote human-resource development and research, than to place emphasis on general scientific literacy. In other words, elitist curricula might just be what developing countries need to lift their economies. Both the purpose of promoting scientific literacy and its meaning are influenced by ideological, philosophical, political, social and economic considerations. For developing nations, decisions have to be made about the nature and form of scientific literacy that is desired. It becomes pertinent to ask how relevant questions about science education for scientific literacy are when malnutrition, unemployment, poverty and disease persist with stubbornness and continue to demand larger chunks of the fiscus. How much should a poor developing country channel towards science education for scientific literacy when governments are faced with the scourge of AIDS, deteriorating health systems and social instability? Is scientific literacy for citizens of many developing nations a major priority at all? The cost of science education continues to rise and for many it is better to be sheltered and fed than to be so-called scientifically literate. As experience in East-Asian countries and Zimbabwe has shown, semi-literate school dropouts have performed better in the informal sector than scientifically literate university graduates.

Even when all this is said, some would still maintain: Is it not better to invest in science education for scientific literacy with the hope that the accrued benefits will in the long run help solve such problems as deforestation, land degradation and unsustainable use of the environment?

These are perennial problems on the sub-continent. What might be needed in designing science curricula is careful balance between science education for a scientifically literate citizenry and science education for economic and human resources development. How exactly such a balance could be achieved will remain open to debate for a long time. This is so because both aspects are critically important for development in Sub-Saharan Africa.

## **Endnotes**

- <sup>1</sup> Three of the teachers' colleges have since been converted to universities. The universities continue to produce teachers as well as offer a variety of other courses in a number of disciplines.
- <sup>2</sup> Zimbabwe's rapid descent into political and economic malaise started in 1997 when the government, in an act of appeasement, awarded 1970s liberation-war veterans gratuities (US\$ 350 million), which were outside budgetary plans. This led to the massive collapse of the Zimbabwe Dollar, which in turn fuelled inflation. The descent into economic ruin was exacerbated when, in 1998, the Zimbabwe government sent troops to the Democratic Republic of Congo to fight a war in defence of the regime of Laurent Kabila. It is estimated that the government spent in excess of US\$ 1 billion in unbudgeted expenses. The descent into ruin was accelerated from 2000 when the government lost a constitutional referendum and ZANU-PF, fighting for political survival, with its appeased war veterans in the forefront orchestrated and implemented a violent and chaotic land reform programme, which led to the collapse of agriculture – the mainstream of the economy. Since then, Zimbabwe has moved from being a breadbasket to a basket case. Its road to authoritarianism, political turmoil and economic ruin has attracted international interest.
- <sup>3</sup> The violent and chaotic land reform programme the government embarked on from the year 2000 led to massive exodus of white commercial farmers, resulting in under-utilisation of agricultural land, which, together with drought, contributed to decreased production on the farms and the subsequent shortage of food. The results of the 2002 population census show that the population of whites (including the commercial farmers) in Zimbabwe decreased to 46 743, a figure well below the over 100 000 whites who lived in Zimbabwe prior to the land seizures.

- <sup>4</sup> One conservative estimate puts the number of professionals (doctors, nurses, teachers, engineers, pharmacists, technologists, accountants, pathologists, university lecturers, etc.) who have left Zimbabwe since 1998 at 550 000. (*Financial Gazette*, 20 March 2008). A UNDP-funded study undertaken by the Scientific and Industrial Research and Development Centre (SIRDC) puts the figure at 479 348. The actual figure could be much higher, as the study acknowledges that it could not contact all Zimbabwean professionals in the Diaspora.
- <sup>5</sup> A Zimbabwe–Cuba cooperation agreement lessened the science teacher shortage. Starting in the 1980s, hundreds of Zimbabweans were sent to Cuba to train as science teachers. In 1995 this programme was relocated to the newly established Bindura University College of Science Education in Zimbabwe, which is now called the Bindura University of Science Education. The university has since produced several hundred science, mathematics and geography teachers.

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# *12. Co-Presentations of Science and Indigenous Cosmologies: A Challenge for Lesotho Science Educators*

Neo Paul Liphoto, Stein Dankert Kolstø,  
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## **Abstract**

This chapter reports on the findings of a research endeavour aimed at exploring the incorporation of indigenous knowledge systems with mainstream school science. The discussion begins by examining the rationale and later the experience of incorporating indigenous knowledge systems in the localisation of the science curriculum in Lesotho. The chapter also presents a brief outline of instructional material that encompasses both the scientific world-view and the traditional one. The material was administered as a treatment to two identical groups of pupils. Prior and after the treatment, pupils' perceptions of lightning and thunder were solicited. This was achieved through questionnaires and interviews. While most pupils did not see a relationship between science and their traditional practices towards lightning, they did however have a positive attitude towards being taught both conceptions. The chapter concludes by arguing for a systemic conceptualisation of indigenous knowledge systems and a collaborative approach to the process of incorporating the two systems.

## **Introduction**

Lesotho is embarking on the process of localising the secondary science curriculum. Rationale for this process is founded on a number of reasons, most prevalent of which is with the country's economic status.

It is extremely expensive for the government of Lesotho and parents to continue paying for the current examination system, which is processed in Cambridge in the UK. Furthermore, Lesotho should localise so as to ensure that the curriculum is responsive to the needs and values of the Basotho as a nation.

Guided by this principle, the National Curriculum Development Centre and the Science Panel have developed a science syllabus for junior secondary level. The new Lesotho Junior Certificate science curriculum, developed under the localisation process, suggests that learner-centred approaches should be used in developing the syllabus. The buzz-phrases for the localised curriculum include the following:

- Practical work through experimentation.
  - Inquiry through investigations.
  - Projects involving analysis, synthesis and designing of articles/items.
- (Ministry of Education, 2002)

The curriculum further acknowledges and stresses that pupils come to school with some knowledge of science, which should not be ignored. Work by Driver (1988), Driver and Oldham (1986), and indeed a lot of research tradition of the 1980s and 1990s in science education, suggests that pupils bring their own explanations of natural phenomena into the classroom. These explanations depend on, among other things, the cultural background of the pupils. Driver and Oldham argue that science educators should be aware of the influence of culture on pupils' conceptions of diverse natural phenomena.

Taking the lead from these arguments, the general lesson objective 14 of the new curriculum states that pupils should have developed awareness and appreciation of the role of science in everyday life, including the Basotho forms of knowledge (Ministry of Education, 2002: 7). Specifically, pupils should be able to identify and apply the scientific knowledge and skills outside classrooms. They should also be able to identify and interpret the relationship between science and the Basotho systems of knowledge. It is hoped that the learners will relate the science they learn through this curriculum to everyday phenomena in their immediate environment and beyond. The previous curriculum version did not have this perspective.

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The study reports on the analysis of the Grade 9 and Grade 10 provisions of the new syllabus. Specifically, the topic 'Static Electricity' was chosen because it clearly illustrates the richness in compatibilities, incompatibilities and conflicts in the conceptions of the nature of lightning and thunder between the scientific world-view and the indigenous knowledge systems (IKS) of the Basotho. It can thus be argued that the new syllabus is inclined towards postmodernity, a philosophical position or conception that accepts arguing, as detailed later in this chapter, that there are diverse cultures within societies and these divergent ways of knowing should not be ignored, but should be considered as epistemological in their own right.

A brief comparison of the old and new syllabi reveals the following changes:

- In the new syllabus, electrostatics starts in Grade 9 and carries on to Grade 10 (this was not the case in the old syllabus).
- The new syllabus has outcomes such as the hazardous nature and importance of lightning, safety measures against lightning, discussion and analysis of local practices, and myths and beliefs regarding lightning.
- The new syllabus takes cognisance of the fact that there are local practices regarding lightning which are entrenched within the Basotho way of life. It goes further to suggest that these practices have to be analysed. The old syllabus does not seem to have taken these issues into consideration. It assumes science to be asocial, ahistorical and universal; a bundle of unblemished facts.
- The new syllabus calls for discussion of myths and beliefs about lightning, among other things. It does not, however, guide the teacher on how to conduct these discussions. The old syllabus simply makes no reference to these provisions.

### **Purpose of the study**

The study aimed to identify challenges related to the co-presentation of IKS with mainstream school science. It further aimed to determine the effect of an instructional approach based on Lesotho secondary school pupils' conceptions of lightning and thunder. The term 'instructional materials' was meant to include materials that have both school science and traditional epistemology. Specifically, within these materials, scientific

perspectives of lightning and thunder were taught together with Basotho epistemology about lightning and thunder. The materials were regarded exemplary in the sense that they represented a different way of teaching compared to the day-to-day methods usually adopted by science teachers in Lesotho and which are aligned with tested constructivist approaches. These teaching approaches of the new syllabus include discussion, reflection, group work, individual tasks, guest presentations and seminars with a traditional doctor.

### **Arguments for enculturation**

The presentation of traditional beliefs and world-views together with mainstream school science, the practice of inviting traditional doctors to talk about their work, and analysis of local practices and myths are indeed foreign pedagogical strategies and classroom discourses in terms of how science has traditionally been taught in Lesotho. The new syllabus demands alternative instructional approaches, which are compatible with its expectations on teaching and learning. This new syllabus recognises and acknowledges the value of various world-views the Basotho have and recognises the true value of Basotho epistemology.

The concept of taking African values and beliefs into consideration is not novel in science education. The Catholic Church, for instance, has been advocating for enculturation for some time now (Amecea Pastoral Department, 1996). This is a conception that recognises that there are true values in African cultures and these have to be integrated into the life of the Church. The Church acknowledges that Africa is endowed with a wealth of cultural values and priceless human qualities. It accepts that Africans have a great sense of a spiritual world. They cherish elderly parents, relatives and other members of the family. It is argued that enculturation will help Christians express their faith in a new and original way. This conception of enculturation is concomitant with Aikenhead's (2000) notion of multiple conceptions, in which he proposed what he calls the 'pluralistic multi-science approach'. Aikenhead's approach aims at enculturating students into their own life-worlds where their lives form and evolve (2000: 245). The authors agree with Aikenhead when he argues that enculturation should not imply assimilation whereby the learners are forced to replace or marginalise their common-sense notions with scientific ones. It was within the spirit of this advocacy and Aikenhead's pluralistic multi-science approach that the materials were developed.

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Ogunniyi (1999) similarly contends that Africans should stay African by investing in their traditional cultures, while at the same time absorbing modern influences. This warning comes at a time when many African countries are experiencing devaluation of their cultures and traditions as a result of religion and education, which are based on Western values and ways of thinking. This absorption of modern values and influences coupled with 'staying African' can create conflicts when the same concept is interpreted differently by both cultures.

### **Research questions**

The following research questions were developed so as to inform and guide the study:

1. What are Grade 9 pupils' conceptions of lightning?
2. How has the use of an exemplary instructional approach influenced Grade 10 pupils' conceptions of lightning?
3. How do pupils deal with the presence of two irreconcilable and incompatible world-views?
4. What are the pupils' perceptions of being taught the two incompatible world-views?

The rationale for choosing lightning and thunder is because static electricity is a foundation for introducing electricity. With the advent of the Lesotho Highlands Development Authority (LHDA), electricity is becoming more readily available in Lesotho. Secondly, lightning strikes are common in Lesotho. As a result, a lot of beliefs, myths and practices are attributed to this natural phenomenon. It is interesting therefore to explore incorporation at this level where the two non-compatible world-views seem to impact differently on the everyday life of the people. Furthermore, it is a challenge to develop an incorporated approach that would result in a curriculum where the two world-views are mutually supportive and complementary. Conversely, the study could serve as an eye-opener for the irrationality of teaching two non-compatible conceptions.

### **Traditional perspectives of lightning and thunder**

In the Basotho traditional thought system, there are two types of lightning: the manufactured and the natural (*maru*, pertaining to clouds). The manufactured type is called *tlalimothoana* (*tlali* for lightning, *mothoana* for

small person). It is believed that this type of lightning can be evoked by a witch doctor using concoctions. When *tlalimothoana* strikes the victim, s/he would have gaping wounds as one struck with a sharp instrument. Invariably, when a person is fatally struck by lightning, or lightning destroys someone's property, this is attributed to *tlalimothoana*. Also, lightning is regarded as a weapon of revenge. There is a belief that the natural form of lightning does not fatally strike people.

According to Ellenberger (1912) and Sekese (1983), when lightning has struck a house or someone in a village, a traditional doctor has to be called to protect the village against evil spirits (in local language: *o thakhisa motse, oa o upella*). Everyone who was in the village when lightning struck (*oa phatsoa*) had to be inoculated and protected through the use of traditional medicines and/or ointments. Milk from the village cows is poured at one place and *lehala* (fresh milk that has been mixed with fluids from some herbs) is made out of this milk. The *lehala* is to be eaten by everyone and part of it used to smear *lithakhisa* (short pegs that have been made from an evergreen plant). The pegs are also sprinkled with a mixture of carbonised herbs, fats and powdered flesh from various animals. The pegs are then driven into the ground at various points round the village. If lightning has fatally struck someone, his/her corpse is to be buried at a muddy place. In the Ugandan tradition, only those elders who have powers to evoke lightning can approach and bury the corpse of a lightning victim (Christoph *et al.*, 1999).

*Scopus umbretta* (Mamasianoke) is a bird that is associated with lightning. This bird is most respected/feared by the Basotho. It is not to be killed or ill-treated in any way. If one kills it knowingly, it is said that lightning would be angry and avenge by killing that person. This idea of personifying and being able to communicate with phenomena like lightning is not unique to the Basotho. In the Ugandan belief system, qualified village elders are capable of summoning lightning and guiding it to punish thieves (Christoph *et al.*, 1999).

The concept of lightning and thunder in the African tradition sketched above is at variance with school science. Traditional conceptions are part of the knowledge that pupils bring to school, and which, some teachers argue, should be replaced by school science.

### **The scientific perspective of lightning and thunder**

Most secondary schoolbooks introduce lightning by an exploration of static electricity. Pupils perform experiments with simple and readily

available items like plastic rods, pens, strips of amber, pieces of paper, a thin stream of water, gold-leaf electroscope, and a Van de Graaf generator (Abbott, 1989; Mpeta *et al.*, 2002). The concepts pertinent to this topic include atomic structure (protons and electrons), separation of charges (positive and negative), attraction and repulsion between electric charges, insulators and conductors, electrostatic induction, ions in the atmosphere, lightning conductors and lightning. The accompanying experiments are such that they appeal to the pupils' inquisitiveness and curiosity. The pupils are motivated into wanting to know why things happen the way they do. Pupils may also be required to come up with their own experiences of a phenomenon of static electricity. This approach is based on the principle of empiricism whereby only observations and experiments decide the acceptance or rejection of scientific statements (Popper, 1963) and explanations. One of the scientific principles used to explain these observations is the electron theory. One therefore has to use abstract conceptions of electrons and protons to explain how a cloud is charged and how it discharges itself.

### **Development and use of the instructional material**

The exemplary instructional material was a unit with the title 'Electrostatics and Current Electricity'. Its development was in line with the Grade 9 and 10 junior science syllabus. The notions of constructivism (e.g. Osborne and Freyberg, 1985), conceptual change (e.g. Posner *et al.*, 1982), border crossing (e.g. Aikenhead, 1996; Costa, 1995; Phelan *et al.*, 1991) and multiculturalism (e.g. Snively and Corsiglia, 2001) guided the construction of the instructional material.

Prior to introducing the pupils to the scientific lessons, a questionnaire was administered which was aimed at soliciting their prior knowledge. This questionnaire will be explained later in this chapter. The purpose of gathering these perceptions was not to use them in the science lessons, but rather to determine whether there was a change at the end of teaching the whole unit. The scientific lessons started with pupils experimenting with rods, pieces of paper, a thin stream of water, etc. and explaining their observations, followed later by a plenary session. The lessons developed from these simple experiments and culminated with a demonstration using the Van de Graaf generator. The process of how a cloud becomes charged and how it discharges itself was then discussed on the basis of the previous lessons – particularly the lesson using the Van de Graaf generator.

Safety precautions against lightning were also examined. The pupils were taken around the school compound to explore safety measures used by the school to protect it from being struck by lightning. The nitrogen cycle was also taught. This approach of teaching science is largely empirical in nature, in that evidence is provided to support a scientific proposition.

### **Theoretical frameworks underpinning integration**

The theoretical underpinnings for the integration include constructivism, multiculturalism and border-crossing. The constructivism framework for the study derives from Vygotsky's social constructivism, as presented in Howe (1996). The social constructivist view of learning acknowledges that culture and social contexts give a child the cognitive tools needed for development. Parents and teachers are the conduits of the culture, including language. Central to this form of making meaning is the learner's community. The theory admits that out-of-school experiences should be linked to school experiences – that is, stories from the environment should be incorporated into classroom activities to provide the learner with a sense of integration of school learning and the community. This implies that a social constructivist teacher encourages learners to work in groups to consider issues, problems and questions that are firmly established in their everyday home experiences. Such a teacher becomes a facilitator of cognitive growth and learning. Jegede and Okebukola (1991a, 1991b) note that socio-cultural phenomenon and constructivism construes learning as a complex and dynamic socio-cultural phenomenon, and that learners from different cultures have notably different experiences of school science as a result of diversified world-view systems.

These theoretical underpinnings guided this study in the sense that prior to being introduced to the scientific perspectives of lightning and thunder, and through traditional knowledge systems, pupils have already gathered information about lightning and thunder. The teacher, in introducing the new conception, will have to anchor it within what pupils already know. It is at this point of anchorage that the complexities of learning occur, since the new and the old conceptions tend to work at odds with one another.

### **Integration**

A considerable amount of research has been done on the interaction between traditional beliefs and school science. On the African continent, in addition to conceptual papers, researchers such as Jegede and Okebukola

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(1991a, 1991b), Ogunniyi (1986, 1987, 1988, 1999) and Kuiper (1991) have presented their findings on issues of culture and school science.

Jegede and Okebukola (1991a, 1991b) conducted a research study to determine the effect instruction has on socio-cultural beliefs hindering the learning of science. They developed the Socio-Cultural Environment Scale (SCES) and found that an experimental group developed a more positive attitude towards science than their control-group counterparts. They claim that the African world-view is one of the socio-cultural factors that plays a critical role in science learning in non-Western culture. They argue that the reasoning pattern dictated by the traditional society regards science as something weird, magical and special.

Aikenhead advocates for what he calls the 'cultural approach to science education'. In his opinion, learning Western science is a cross-cultural event for most Aboriginal students. In pursuance of this approach, he (along with Aboriginal elders and science educators) developed units that integrated Western science with Aboriginal science. He argues for meaning making from what he calls 'cultural perspective meaning making'. In his opinion, people's cultural identities may be at odds with the culture of Western science to varying degrees.

Aikenhead further warns against trying to make local knowledge conform to Western epistemology, which is endemic to school culture. This, in his opinion, would result in disrespect of the Aboriginal culture. One wonders as to the effect the integration of Western science and local knowledge about lightning and thunder would have on the respect pupils have for their culture.

### **Border crossing**

The research is embedded in cultural border crossing. Border crossing is a conception that conceptualises the transition between a student's life-world and school science as a cultural border crossing (Aikenhead, 1996). Within the framework of this study, border crossing will be seen as a back and forth movement between cultural conception and scientific world-view; where in one context the learner resorts to traditional mode of interpretation, while in another the same learner adopts the scientific world-view. Aikenhead claims that border crossing can be smooth, manageable, hazardous, or impossible. It is our aim to establish whether the integration makes border crossing smooth or difficult.

Concept construction, as described by Osborne and Freyberg (1985), is undergoing criticism from Cobern (1994) and proponents of cultural perspectives such as Aikenhead (2000). Osborne and Freyberg argue that children will change their ideas and adopt new ones depending on the intelligibility, plausibility and fruitfulness of the new ideas. The new science syllabus suggests some form of comparison. We want to argue that the three parameters mentioned above (intelligibility, plausibility, fruitfulness) do make sense as a basis for comparison. It is also of paramount importance to premise the comparison within a given context because it is not unusual that a conception might appear implausible in the scientific world-view, but very plausible in the traditional world-view. Ogunniyi (1988) puts it succinctly when he states that the traditional African world-view is logical and valid within its controlling image context. In his opinion, Aikenhead construes that such a perspective of learning (as expounded by Cobern, 1994) amounts to assimilation, which means that pupils are forced to replace or marginalise their common-sense notions with scientific ones. Cobern argues that within the conceptual change paradigm there is an embedded assumption that scientific conceptions are superior to other forms of knowing. He goes on to claim that conceptual change makes little sense when pupils are expected to adopt scientific world-views which in their opinion have little scope and relevance to their everyday world. In Cobern's opinion, world-view is about metaphysical antecedence to specific views that a person holds about natural phenomena, whether one calls those views common sense, theories, alternative frameworks, misconceptions, or valid science. He perceives a world-view as the total sum of whatever number of cultural components a person embraces. In this day and age, a Basotho child is exposed to various world-views in her/his life, and as such it is not out of place to allow the child to experience the milieu of world-views within school science.

### **Integration: Experiences from other parts of the world**

The integration of traditional beliefs and world-views within science teaching, employing culture-sensitive teaching methods, and the analysis of local practices and myths are foreign pedagogical strategies and classroom discourses in terms of how science has traditionally been taught in Lesotho. Compounded with the problem of integration is the insufficient conceptualisation of the nature of traditional world-views and their slippery methodologies, as compared with the scientific ones that are well coded.

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There is an outcry in many countries to explore ways of incorporating IKS in mainstream school science (Curriculum 2005 – South Africa, the Alaska Native Knowledge Network – Alaska, Implementing the Common Curriculum in Aboriginal Schools Project – Australia, Cross-Cultural Science & Technology for Northern Saskatchewan Schools – Canada). Various educationists from different fields are debating the integration in South Africa. Onwu and Mosimege (2004) state that there is a need for a mechanism of integrating IKS into science curriculum in a mutually supportive and inclusive way. He goes further to suggest that there should be a proper conceptualisation of IKS as an epistemology and an understanding of its methods. We should also appreciate the relationship between IKS and scientific world-view. The authors would argue here that for a comprehensive understanding of IKS, one has to consult with elders, who are the custodians of this knowledge and its methods. Again there should be cooperation between these keepers and scientists with the purpose of cultivating national benefits from both systems and realising linkages between them.

As mentioned elsewhere in this chapter, pupils and teachers are required to discuss, analyse and conceptualise the Basotho conceptions and practices of lightning and compare these with the scientific world-view. The merging of the two perspectives may amount to conceptual change or concept proliferation. Aikenhead (2000) advocates for conceptual change, pointing out what Mill (1868) and Feyerabend (1975) argue that people are different and their opinions should be allowed to flourish. Feyerabend would further like to see astrologers and witches having equal share in society's resources, and have current scientific theories run concurrently with other incompatible ones. Aikenhead's concept of proliferation, even though reminiscent of Mill and Feyerabend, is dissimilar. According to Aikenhead, the 'concept model suggests that a new (scientific) concept is constructed within a new (scientific) context and added to a student's repertoire of specific context or to a student's conceptual profile' (2000: 249). Drawing from Ogawa (1995: 221), Aikenhead explains that a multi-science view adds context to a student's repertoire of life-world contexts, with each context having an identifiably different view of natural phenomena (i.e. concept proliferation).

Some researchers have done some work aimed at conceptualising, harmonising and bridging the gap between both world-views and putting them together, hoping to come up with a 'culturally responsive curriculum'.

Figure 1 (from Stephens, 2000) shows some of the significant constituents of both world-views and the interfacing elements. Stephens goes further to suggest that a culturally responsive curriculum has to do with presenting science with the whole of cultural knowledge in a way that embodies that culture, and with demonstrating that science standards can be met in the process. We would also argue that the presentation should not be such that traditional knowledge becomes a subservient to the scientific world-view. It is critical that IKS must be taken and considered as a veritable body of knowledge in its own right with its methodology and epistemology. More often than not the two world-views have incompatible methodologies. We concur with Onwu and Mosimege (2004) in that one should not subject IKS to the same verification process – which is a procedural principle in Western science – as we usually do with respect to Western science. We have to avoid the common tendency of looking at IKS with the same lens of judgement that we would use when viewing Western science.

A critical look at the Venn diagram reveals that there are commonalities as well as differences between the world-views. The intersection would include those cultural practices and experiences that can be explained using school science. The authors wish to apply this model to unpack and interrogate the Basotho perception of lightning.

### **Non-interfacing planes**

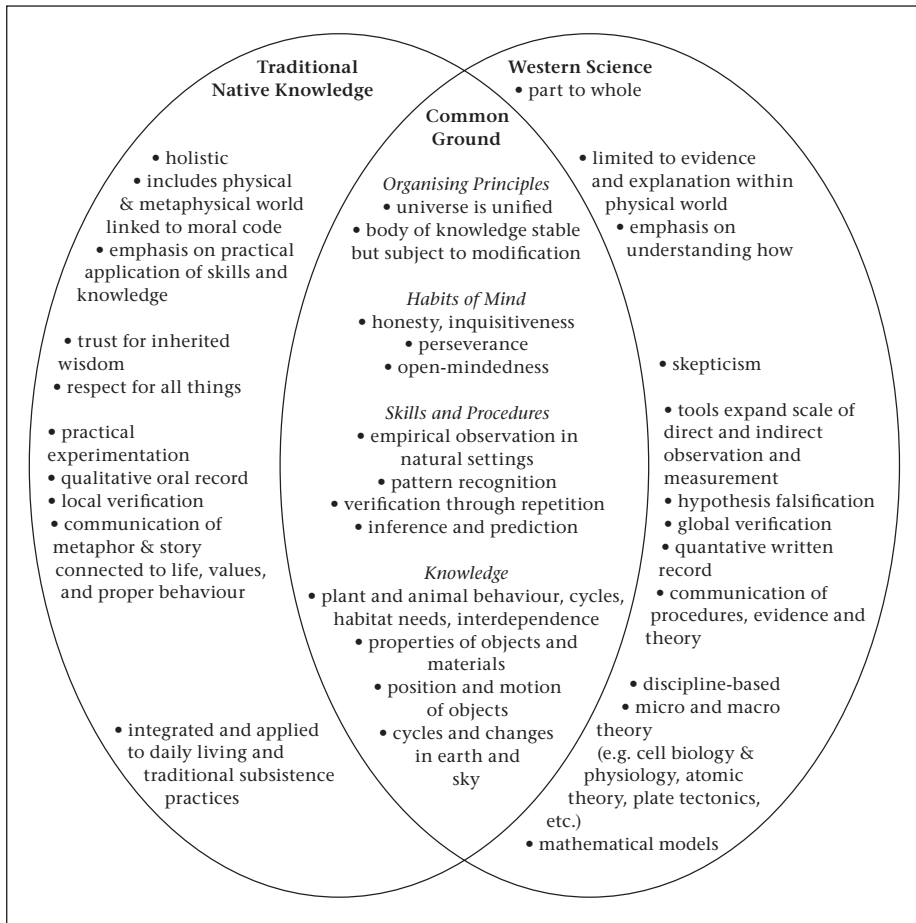
Starting with the non-interfacing aspects of lightning, focusing in particular on the holistic nature of traditional knowledge, people see lightning as a natural phenomenon while also having animalistic attributes (it can be angry, it can be summoned, it lays eggs, etc.). Moreover, there is the ingredient of respect accorded to lightning and its associate bird, *Scopus umbretta*. The scientific world-view conceives lightning as a physical phenomenon whose explanation at the micro level requires electron theory.

### **Interfacing plane**

At this plane, both systems of knowledge, the IKS and western scientific world-view grow and are modified depending on the nature of discourse and arguments engaged. Looking at lightning, traditional doctors apply both knowledge systems to protect property and people. For example, they use the concept of a lightning conductor together with their concoctions to protect people and property. Further still, both systems associate lightning with empirical observations in natural settings. In the Basotho

case, these natural settings would comprise, among others, water, tall trees and high grounds.

**Figure 1: Significant constituents of scientific and traditional world-view\***



\* Source: Stephens (2003)

### Anti multi-science sentiments

The authors are conscious of the expressed criticisms of the theoretical framework within which this study is anchored. The critics include Osborne (1996), Jenkins (2001), and Good and Shymansky (2001). For example, Good and Shymansky argue that conserving local practices and

protecting individuals' pre-scientific ideas about physical causality are not priorities for science. Our analysis has reservations against this indifferent stance on the grounds that it ignores the values and belief systems of any individual, including those that uphold the scientific belief systems. In their view, the integration should be such that Western science is compared with other systems of knowledge in juxtaposition. Aligning themselves with critics of postmodernism, like Gross and Levitt (1994), the critics of multiculturalism and alternative conceptions of science argue that postmodernism refers to the rejection of universals or meta-narratives, final meaning, the idea of progress, logic and reason. It is our contention that the integration should benefit the learners and help them to be useful members of their own communities. While we acknowledge the basis for the argument by these critics, we would also argue that the scientific world-view describes with high predictive validity what would happen, but is limited in telling people how to behave (Aikenhead, 2000). The integration would therefore help one to develop in a holistic manner.

### **Procedure**

A questionnaire entitled 'My Ideas about Lightning and Thunder (MILT)' was developed. The purpose of the questionnaire was to seek pupils' conceptions of lightning and thunder. This questionnaire, adopted from an earlier instrument by Ogunniyi (1999), was administered to all the subjects as a pre-test and a post-test. It was a modified form of a cloze questionnaire. The instrument helped the researcher to find out pupils' conceptions of lightning and thunder and also to determine the effect of the exemplary instructional approach in affecting pupils' conceptions. It was qualitatively analysed.

Interview schedules were developed and administered. The science teachers of the sample school were interviewed to establish their opinion about the integration of IKS within the science curriculum. The researcher also had a chance to visit the traditional doctor.

Ten pupils from the experimental group were randomly selected and interviewed. The interview sought pupils' opinions about being taught two incompatible world-views as well as their perception of the integration. They were also asked about the source of their prior knowledge about lightning.

## Findings

### **Discourses during the traditional doctor's presentation and plenary sessions**

To incorporate the traditional perspectives of lightning and thunder, a traditional doctor was invited. When the pupils were informed that the doctor would be coming, there was a lot of enthusiasm – not only from the pupils, but also from other teachers of the school. The doctor's presentation started with 'codification' of lightning as perceived by the Basotho, whereby there are two types of lightning – artificial lightning and cloud lightning. He focused more on the artificial type explaining how he creates lightning, the type of weapons he has to carry, the attire and the return after completing his distractive mission. He went on to explain safety procedures against lightning. During question time, most of the questions from the pupils were confirmatory ones. They wanted to verify what they had already been told about lightning by peers, grandparents and other members of the community. Examples of this type of questions included the following: Can lightning steal? Does lightning lay eggs? Have you used lightning to kill other people? (The doctor was reluctant to respond to this one, but the message was clear.) The *why* and *how* questions were very few.

Concerning safety procedures, the doctor talked about incision and inoculation (administered by himself ), and that he could be invited to protect property against lightning. Pupils were discouraged from killing *Scopus umbretta* because its dried flesh is used by doctors when mixing their lightning ointments. Pupils were further discouraged from playing with water during a thunderstorm (lightning 'loves' splashed water and sweat), and they should not stand under tall trees – particularly the willow tree (lightning lays eggs on willow tree). The researcher had a chance to visit the doctor. At his yard, he had a long wooden pole placed upright, at the end of which is a sickle smeared with a carbonised concoction. By combining the scientific ways of protection with traditional medicines, the doctor seems to have undergone acculturation – a process whereby a person appropriates features of another culture that are useful.

During the plenary session aimed at analysing and comparing the two knowledge systems it was noted that pupils could identify gaps and overlaps between the two. They could see that in both systems lightning is associated with water, tall trees and sweat. However, the pupils could

notice that the two systems differ in explaining the relationship. While the scientific one was based on induction and electron theory, the traditional one was founded on animalistic behaviour of lightning (lightning loves water splashes).

### Pupils' conceptions of lightning

Pupils were given a questionnaire in which they had to read a story and respond on whether they agreed with the statements given below the story. There were eight stories in all, the first four of which had different themes. Story 1 was about a traditional doctor who has been struck by lightning while trying to divert a thunderstorm; Story 2 focused on a hut that had been struck by lightning leaving a pool of 'water' that some people claim was urine left by lightning. Story 3 was about the consequences of killing the bird of lightning (*Scopus umbretta*). Story 4 was about protection from lightning. We provide a typical example of one of the stories in the box below. It should be recalled that MILT was administered as a pre-test and a post-test.

#### **Story 1 excerpt from lightning and thunder questionnaire**

During a thunderstorm, Mr Ngakamatsetsela, a well-known traditional doctor, went out of his house holding a metal spear and pointing it in all directions. He was suddenly struck by lightning. People say that:

	SA	A	DK	D	SD
(a) He was not a qualified traditional doctor (ke ngakana ka hetla).					
(b) Other stronger doctors bewitched him.					
(c) His spear conducted charges through him.					

What do you say? \_\_\_\_\_

Code: SA = Strongly Agree (5); A = Agree (4); DK = Do not Know (3); D = Disagree (2); SD = Strongly Disagree (1).

The pre-test analysis shows that out of a total of 70 students, 63 agree that the doctor was struck by lightning because he was not a qualified traditional doctor and that other stronger doctors had bewitched him. To elucidate typical pupils' responses, I present below an example from

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a pupil nicknamed Thato. The pre-test analysis showed that Thato agrees with (a) and (b), and is undecided on (c) (she opted for DK). In responding to the question *What do you say?*, Thato defended her choice of options. She goes on to say:

Mr Ngakamatsetsela was not a strong doctor and those who are wise showed him the way of how to be a traditional doctor.

In responding to the same story, the post-test analysis showed some shift. This time Thato strongly disagrees with (a), strongly disagrees with (b) and strongly agrees with (c). Again, she supported her choice in the write-up.

From her responses, we may deduce that prior to being taught about lightning from the scientific perspective, Thato was thinking in terms of traditional cosmologies. She was not aware of another conception of lightning – that which has to do with electrical charge.

However, after being taught about a charged cloud discharging, there seemed to be an apparent shift to think in the scientific mode. She writes:

He should have not taken spear because it's metal, when clouds are charged and there is a thunderstorm, he should not take the spear because the electrons from the clouds might be conducted to the spear.

**Story 2 excerpt from lightning and thunder questionnaire**

During a thunderstorm, lightning struck one hut. After the storm, people came to inspect the hut. There was a pool of water at one place in the hut. Some people said that:

	SA	A	DK	D	SD
(a) This was not water, but the urine of lightning.					
(b) It was possible that this was water.					
(c) The owner of the hut should call a traditional doctor to come and throw divining bones (a tl'o laola)					

Analysis of findings on this story reflect the same distribution as for Story 1. Most pupils responded in traditional terms. Most opted for (a) and (c). The principle of scepticism (a scientific aspect) and exploring the possibility

that the liquid could be water was not considered. However, more than 50% of those that opted for (b) still believe that a traditional doctor should be called to provide an 'authoritative' explanation.

For this story, Thato had opted for DK in (a) and (b) and SA for (c). In her narrative, she writes:

It's good for the owner of the hut to call a traditional doctor and throw divining bones 'coz someone bewitched him.

The post-test analysis showed a shift. She opted for SA in (a) and (b) and SD for (c). In her write-up she goes on to say:

If he calls a dr. he is just going to say 'they were trying to kill you but you are lucky b'coz you called me'. This was just urine of lightning.

This is a sarcastic way of stating a non-belief in the authoritative nature of traditional doctors. Paradoxically, she still believes – and strongly, for that matter – that the liquid was urine of lightning.

Prior to the intervention, Thato is thinking in the traditional cosmology paradigm. She is unsure as to whether the liquid is water or urine of lightning. To verify whether the liquid is water or not, she is suggesting that a traditional doctor had to be called. However, after the intervention, Thato shows what the authors would call 'proliferated thinking'. She strongly agrees that the liquid was not water, but urine of lightning (traditional thinking). Again Thato strongly agrees that there was a possibility that the liquid was water (scientific mode – allowing other possibilities). However, she does not support the idea of calling a traditional doctor to 'investigate'. Thato is seen to be responding using both traditional and scientific wisdom with ease. For her it does not matter whether she is thinking in terms of IKS or a scientific world-view.

### **A general trend**

Prior to the administration of the instructional material, more than 90% of the pupils responded in traditional terms for all eight stories. For the first story, 36% of the pupils opted for (c), which is a scientific explanation. The narrative section of the story was left blank. However, after having been introduced to the scientific perspective of lightning, 55% still responded

in traditional terms, and 32% responding using scientific terms; while 20% responded using both conceptions.

Pupils strongly adhere to the idea of a traditional doctor being able to protect people and their property against lightning. This adherence is so strong that they would rather use the scientific methods of protection together with traditional medicines.

### **Emerging issues**

The pupils bring to the classroom their own conceptions of lightning. These conceptions are derived from their culture and contexts. Some of the conceptions are at odds with the scientific world-view, while others are not. However, the learners seem to compartmentalise these variant conceptions, rather than bring them to contradict each other. This may be interpreted as concept proliferation, as perceived by Aikenhead.

The scientific explanations of lightning do have a bearing on those apprehensions that pupils bring to school science classrooms. The authors wish to argue that pupils are reluctant to apply scientific methods to interrogate the assumptions and methods of IKS as this may be interpreted as lack of respect to the elders and custodians of IKS. This is reflected by the way the pupils interacted with the doctor. They were not prepared to ask him questions that would require him to demonstrate and verify his statements. This calls for a need to explore how pupils could be guided in raising critical questions at the right time, particularly during a science lesson.

Giving pupils both perspectives of the same concept helps them to navigate between the conceptions. The navigation is aided by the context and usefulness of the conceptions within that context.

The use of the instructional material will result in both conceptual change and concept proliferation. These two processes should therefore not be seen as being mutually exclusive.

### **Interview with the chairperson of the National Science Panel**

The chairperson of the National Science Panel was also interviewed with the purpose of determining the extent to which the panel has conceptualised the integration.

The chairperson perceives a relationship between science and the Basotho forms of knowledge. She argued that there are similarities and relationships between the two systems of knowledge. In her opinion, the

relationship is elucidated in the way traditional doctors protect their yards against lightning. She agreed that the panel has not yet conceptualised the nature of Basotho forms of knowledge. She did, however, acknowledge the urgency of doing so. Furthermore, she is aware that both systems of knowledge could conflict. Not to confuse learners, she suggested that it would be wise for teachers to focus on aspects of the Basotho forms of knowledge that could be explained using scientific processes.

## **Discussion**

The study shows that pupils continue to adhere to their own traditional conceptions of lightning. This is not a new phenomenon. Literature that shows that pupils bring their everyday experiences into school science abound. Literature further shows that this phenomenon persists despite conceptual change teaching strategies aimed at trying to assimilate pupils into the scientific world-view (e.g. Aikenhead, 2000). As alluded to elsewhere in this study, there was a conscious presentation of traditional perspectives of lightning and discussion whereby learners could critique their traditional conceptions against the scientific ones; which, according to literature, are more plausible and fruitful. A simplistic explanation for this could be that traditional doctors, like society elders, are respected and what they say is normally taken without questioning. A contentious explanation could be that these conceptions are perceived by learners to be intelligible, plausible and indeed fruitful in their everyday contexts.

The pupils do not seem to experience any cognitive conflict in dealing with two irreconcilable and incompatible world-views. This could be explained in terms of what Aikenhead and Jegede (1999) call collateral learning. Aikenhead and Jegede explain collateral learning as a process whereby a learner in a non-Western classroom constructs, side by side and with minimal interference and interaction, Western and traditional meanings of a simple concept. It would be interesting to interrogate the learners' responses in terms of the four types of collateral learning identified by the Aikenhead and Jegede.

## **Reflection on the use of the instructional material**

The intention behind the material was, among other things, to provide the pupils with an opportunity to manipulate instruments and predict an outcome of an event prior to performing an experiment. This presupposes availability and adequacy of relevant apparatus. This was not the case at

the study school. Some apparatus had to be borrowed from the National University of Lesotho and a nearby school. Some pupils started performing their own investigations with the apparatus. Some of these were tolerated as long as they were within the context of the aims of the learning process at the time. The presentation by the traditional doctor also took more time than anticipated – a result of the enthusiasm shown by the pupils.

## **Conclusion**

Pupils have their own conceptions of lightning, which should not be seen as a hinderance to the teaching and learning of science. While most of these conceptions are incompatible with school science, some of them are in line with scientific conceptions and their incorporation would not only enhance the understanding of school science, but would also be a subsidy to traditional wisdom. There is a need to have a common conceptualisation of IKS and its incorporation with school science. This conceptualisation could be achieved by first having a constructive dialogue with various experts of the traditional world-view and elders who are the custodians of this knowledge. The IKS that should be incorporated should have proved itself to have some benefit to the indigenous people.

Exemplary teaching in an environment seeking co-presentation of science and indigenous knowledge demands thorough preparation on the part of the teacher.

## **Recommendations**

Those features of indigenous knowledge that interface with the scientific world-view should form the basis for incorporating IKS with school science. The study showed that there are aspects of IKS within the topic of lightning that interface with the scientific world-view. In both systems, lightning is associated with water and clouds. Both systems acknowledge that people should not handle water during a thunderstorm. They both concur that it is not safe to stand under tall trees during a thunderstorm. It may be argued that this model of incorporation would subject indigenous knowledge to subservient status when compared with the scientific world-view. This may not necessarily be the case. In fact, the scientific world-view would be applied in the apprehension of conceptions experienced within the framework of indigenous cultures and values. Moreover, school science would be used to benefit indigenous knowledge.

The non-interfacing section should be analysed and subsequently incorporated within school science on the basis of its usefulness to community. There are features of indigenous knowledge whose purpose is to instil and perpetuate the principle of harmonious connectivity between humans and nature. Clearly, issues that promote this should be integrated within school science. Some of these valued practices may not sound so palatable to some communities because their functionality is contextual. These values have been embraced by the Basotho as a nation for centuries. For an example, the practice of honouring and venerating tribal emblems or totems is perceived to be barbaric and savage by some people such as Ellenberger (1912); while one of the co-authors on this chapter has a hare as his tribal emblem. For this author the practice is not only 'normal', he is also proud of it.

It is common knowledge that witchcraft is one of the socially repugnant traditional practices, and it is not acceptable in any society, including that of the Basotho. Any person caught or suspected of witchcraft is forcefully removed from a village. A person who evokes lightning to kill or destroy other people's property is regarded as a witch. Whether there is any empirical evidence to suggest that a witch can manipulate lightning (which in most cases a witch would dare provide), learners should be discouraged from perceiving that activity as of any use to humankind.

Teachers should be prepared such that they have a common understanding of the nature of science and that of IKS. It is teachers who at the end of the day have to contextualise teaching and create a culturally inclusive learning environment.

In as much as science reflects on its methodologies and falsifies itself, the indigenous knowledge system would have to look into itself. Science is where it is now because philosophers of science critiqued its methodologies as well as its nature. An IKS should do the same.

The lessons and teaching/learning activities could have accorded students more space to explain and share their ideas as a class, and as a means to generate and provide more opportunities for students to explore their own ideas, in line with social construction of knowledge (Aikenhead, 2000). Furthermore, some of the uncertain and or contentious conceptions of students could have been explored through research (perhaps in their communities) for further explanation and/or laboratory testing as a means to socialise them into testing, questioning and elaborating knowledge claims.

Finally, in as much as the National Science Panel translates the national goals into curriculum processes in response to policy statements, it should also identify those aspects of IKS that interface with a specific school science theme and apply a systemic approach to the incorporation process.

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## Appendix 1: The new Junior Secondary Science Syllabus

Content	Learning outcome – Candidates should be able to:
<p><b>8.0 Electrostatics (Form B)</b></p> <p>Positive and negative charges; positive (+) and negative (-) signs used to represent charges. Charging by friction. Electrical conductors and insulators. Charging by induction.</p>	<p>Describe how to detect charges using an electroscope. Describe charging by friction. Distinguish between electrical conductors and insulators. Describe charging by induction.</p>
<p><b>9.0 Current Electricity (Form B)</b></p> <p>Circuit symbols: switch, ammeter, bulb, voltmeter. Unit of: current – amperes (A), voltage – volts (V) Circuit diagrams: draw and interpret simple circuit connections, reading of ammeter and voltmeter.</p>	<p>Describe how to connect voltmeter and ammeter in a circuit. Describe how to connect simple circuit bulbs, cells, ammeter and voltmeter. Measure current and voltage in a circuit containing bulbs, cells, switch, ammeter and voltmeter. State the SI units of current and voltage. Illustrate simple circuit diagrams containing bulbs, cells, switch, ammeter and voltmeter. Interpret simple circuit diagrams containing bulbs, cells, switch, ammeter and voltmeter.</p>
<p><b>8. Electrostatics (Form C)</b></p> <p>Effects of charge. Lightning: causes, importance – nitrogen cycle. Safety measures – earthing. Lightning conductor. Application of electrostatic. Local practices about lightning, e.g. thakhisa.</p>	<p>Describe effects of charge. Describe how lightning is caused. Describe the hazardous nature of lightning. Describe the importance of lightning. Describe safety measures against lightning. Identify everyday examples where the phenomenon of electrostatics is evident. Analyse some local practices and beliefs regarding lightning.</p> <p>(Notes: effects of electrostatics – dry hair and synthetic hair, feeling shock, seeing sparks; discuss some myths, beliefs about lightning)</p>

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<p><b>9.0 Current Electricity (Form C)</b></p> <p>Series and parallel connection of circuits.</p> <p>Effects of series and parallel connections.</p> <p>Applications and everyday examples of circuits: torch, wall-watch.</p>	<p>Illustrate a series connection of bulbs in a circuit.</p> <p>Illustrate a series connection of cells in a circuit.</p> <p>Represent a parallel connection of bulbs in a circuit.</p> <p>Represent a parallel connection of cells in a circuit.</p> <p>Illustrate parallel and series connection of circuits using symbols.</p> <p>Describe the effect of series and parallel connection on brightness.</p> <p>Identify everyday examples of electrical appliances.</p> <p>State examples of devices in which simple circuits are used.</p>
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# *13. Knowledge and Process Skills Used by South African and Norwegian Students to Perform Cognitive Tasks on Gases*

Øyvind Mikalsen and Meshach Ogunniyi

## **Abstract**

The study reported in this chapter is part of a large-scale study exploring process skills used by South African and Norwegian Grade 8 to 10 students in performing various cognitive tasks. Specifically, this study deals with the knowledge and process skills deployed by Grades 8 and 9 South African and Norwegian students to solve problems on gases. The students' responses to an assessment instrument known as 'My Ideas of Gases' (MIOG) are analysed quantitatively and qualitatively in terms of two different types of process skills; namely, basic or classification/conception skills and high-order or application/decision-making skills. The findings show that while the average score in terms of knowledge about gases for both groups of students is 38.0%, there is a great variety in the mean scores on the individual questions. Also, the same sets of questions have proved either easy or difficult for both groups. Overall, 38% and 39% of the students in both countries have been able to demonstrate the classification/conceptual and application/decision-making process skills, respectively, needed to perform cognitive tasks demanded by the assessment instrument on gases. The implications of the findings are highlighted in the chapter.

## **Introduction**

This study is motivated by the general under-achievement in school science in Norway and South Africa. The underlying assumption in this

study is that such under-achievement in school science probably starts in the earlier grades (Mikalsen and Ogunniyi, 2005; Ogunniyi 1999, 1996; Ogunniyi and Mikalsen, 2003; Ogunniyi and Mikalsen, 2004). The issue of under-achievement in science is a global phenomenon that has been of major concern for science educators for several decades (e.g. Aikenhead, 2003; Chang *et al.*, 2003; Driver *et al.*, 1996; FRD, 1996; Kampourakis and Tsaparlis, 2001; Lie *et al.*, 1997; Lee *et al.*, 2001, Ogunniyi, 1993; Sjøberg, 2002; Swain, 2000). Despite the contextual differences between Norway and South Africa, the results of the Trends in International Mathematics and Science Study (TIMSS) revealed similar patterns of performance; that is, that only a minority of the students in both countries performed well and that certain topics which were found difficult by students in one country were equally difficult for students in the other country (see, for instance, FRD, 1996; Lie *et al.*, 1997; Sjøberg, 2002; Swain, 2000; TIMSS, 1996).

Assessment of students' understanding of various natural phenomena is one of the most contentious activities in the field of education. The low enrolment in scientific and technological fields in higher institutions as a result of students' poor performance in science at the lower levels of the education system is a worldwide trend. The recently released results from the international comparative assessments studies of the Programme for International Student Assessment (PISA), TIMSS, the Students' Achievement in Science (SAS) study and the Relevance of Science Education (ROSE) project indicate that the situation has not yet improved (Lie *et al.*, 1997; Riley, 1998; Schreiner and Sjøberg, 2004; Sjøberg, 2002; Swain, 2000). According to TIMSS (1996), South Africa had the lowest score in science for Grade 8 out of all 41 participating countries. While South Africa did not participate in TIMSS 2003, Norway scored slightly above (494) the international average (474) in that study (TIMSS, 2003). What is perhaps alarming for Norway, is the huge negative change in the result for Grade 8 from 1995 to 2003; only Sweden being behind. For Grade 4, Norway has an even larger decline in results for science from 1995 to 2003, pointing to a negative trend in Norwegian schools; even at the primary level. In the PISA study, Norwegian 15-year-olds scored according to the international average (PISA, 2003). However, South Africa did not participate in the last PISA survey.

Reactions to the outcomes of assessments are a worldwide phenomenon. As a reaction to the results to the TIMSS results in 1995 (TIMSS, 1996), the US Secretary of Education (Riley, 1998: 1) contends that:

## *Knowledge and Process Skills Used to Perform Cognitive Tasks on Gases*

These are very important results from the Third International Math and Science Study concerning our nation's 12 graders. These results are entirely unacceptable, and absolutely confirm our needs to raise our standards of achievement, testing, and teaching, especially in our middle and high school – and get more serious about taking math and science courses.

Similar reactions were expressed by many countries, including South Africa and Norway. But while most science educators in these countries are well aware of the importance of process skills to learning, and the fact that our learners are under-performing in science (FRD, 1996; Khan and Rollnick, 1993; Ogunniyi, 1999; Lie *et al.*, 1997; TIMSS, 1996), only a few are addressing this subject in their research endeavours. Also, despite the usual public outcry and finger-pointing exercise after the publication of the results of such assessments, very little is being done in terms of systematic research to determine the nature of the problem or what to do about it. No doubt, the factors responsible for students' under-performance in science are diverse and complex (Aikenhead, 2003; Black, 1998; Driver *et al.*, 1996; Johnstone, 1991; Ogunniyi, 1986, 1996; Swain, 2000), and it is practically impossible to capture all these factors in one study. However, among many factors that have been associated with student under-achievement, the most frequently mentioned in the literature in recent years has been that while students may be able to answer questions demanding recall or recognition of knowledge, they tend to perform poorly in questions requiring explanation or critical thinking skills (Kampourakis and Tsaparlis, 2001).

The ability to provide valid explanations or reach meaningful decisions on any subject matter is not only a critical feature of science and science education (Taber, 2003), but perhaps of life in general. Hence, our position in this study is, first of all, to start with the exploration of students' present ideas about various phenomena (Ausubel, 1970; Gagne, 1970), depicted in their science curricula through a battery of diagnostic instruments before seeking instructional strategies to remedy the misconceptions they hold about such phenomena (Ebenezer and Connor, 1998; Taber, 2003). The hope, in line with the tenets of critical theory, is that by exploring students' explanations and by engaging them in problem-solving activities, we might be in a better position to appreciate their own perspectives and to achieve meaningful dialogue that could result in tangible outcomes than would have been the case if we had ignored their ideas or maintained a

superior vantage point in the teaching–learning process. Also, as Bruner (1960) and Driver and Erickson (1983) have contended, students must understand the basic or fundamental concepts of a discipline if they are to understand the structure of that discipline. But how can they master such basic concepts in the absence of some meaningful dialogue or the opportunity to express their viewpoints? It is against this background that this study has been carried out.

Although there is great concern in Norway and South Africa about students' poor achievement in science, nobody seems to know what to do to solve the problem. One often hears sweeping generalisations in the media or at conferences such as: We know that students are under-performing in science. We know that boys perform better than girls in science. There is nothing new about students under-performing in science, etc. But the questions however, are: How much do we really know about student under-achievement in science? If we do know, have we solved the problem? What effective instructional strategies are currently available to address the perennial problem of student under-achievement in science? Although these questions are important, they are not the primary focus of this study. Specifically, the central concern of this study is to determine Norwegian and South African students' understanding of gases – a topic of high relevance in both countries in question. Grades 7 to 10 form the inter-phase between primary and secondary schools in both countries and, as has been pointed out in a number of studies, it is in this transition stage that students' under-achievement in science is most noticeable (Chang *et al.*, 2003; Driver *et al.*, 1996; Kampurakis and Tsapalis, 2001; Ogunniyi, 1996). For the same reason, this transition stage has been the focus of most large-scale national and international studies (Lie *et al.*, 1997; Ogunniyi, 1999; Riley, 1998; Sjøberg, 2002).

This study draws inspiration from the constructivist epistemology; particularly the Piagetian developmental theory as explicated to science education by Shayer and Adey (1981) in terms of assessing the match between curricular materials and learners' cognitive abilities. It also borrows ideas from Bruner's (1960) theory of readiness – i.e. what learners at a particular cognitive level, age, stage, state, experience – as well as Ausubel's (1970) notion about the role of intensity of exposure in solving a problem with little or no assistance from a teacher. The study has also benefited from the constructivists' belief that construes learning as an active construction of ideas based on interactions with one's immediate

environment (Tobin, Rennie and Fraser, 1990) and the fact that students' understanding of, or predisposition to, the study of school science is, to a large extent, conditioned by their prior or existing knowledge. This implies that it is better to identify the knowledge of a given phenomenon currently held by students than assume the behaviourist *tabula rasa* principle at the commencement of formal instruction (Ausubel, 1970). In this regard, our first priority has been to explore students' conceptions of gases as a prelude to determining the next phase of the study; i.e. the kind of remedial instructional strategy that might prove facilitative in ameliorating their invalid conceptions of the topic in question. Unlike the TIMSS, and in view of contextual differences, the emphasis is not a direct comparison of the two groups of students *per se*, but to find out what aspect(s) of the topic they find difficult and then to seek a suitable instructional approach to address the problem as the study progresses. This chapter reports the preliminary findings resulting from our analysis of the students' conceptions rather than the outcomes of remedial instruction that would be carried out afterwards.

By choosing two countries on either side of the equator it is hoped that some general issues of mutual interest might emerge that have curricular, instructional and research implications, not only for the two countries but also for others facing similar problems. Still, one has to be aware that the educational basis in the two countries is not the same. While Norway is a stable and rich country with a well-organised educational system, South Africa as a Sub-Saharan post-apartheid country faces quite a number challenges. In view of this, it is important to find out why similar trends in performance are encountered. The authors have a nagging suspicion that the problem of under-achievement in science in both countries (though exacerbated by the factor of poverty in the case of South Africa), perhaps goes beyond just the availability or unavailability of resources to that of the intellectual challenge of optimising resources. According to Vitta (1993: 30), 'while the quantity and quality of resources are important, no less is their optimal use'. In the authors' view, the place to begin is not to interrogate the nature of resources *per se*, but to seek ways and means that could help in determining the status of potential intellectual capital necessary for problem solving, which in turn is dependent on the possession of critical process skills. Hence, our focus in this study is to explore the nature of the embryonic development of these process skills among Grades 8 and 9 students in South Africa and Norway.

## **Aim of the study**

As has been pointed out, the central concern of this study is to determine conceptions of gases held by Grade 8 and 9 South African and Norwegian students. An additional aim has been to identify the process skills they use when solving problems on gases. The needs for learners to possess process skills are greatly stressed in both the curriculum and research literature (Cavallo and McNeely, 2003; Department of Education, 2002; Johnstone, 1991; National Research Council, 1996). This study tries to reveal the thinking process skills behind the students' performance on the tasks on gases. It is hoped that the findings of this study will contribute to a better understanding of the cognitive skills that students at this level of the education system are likely to use when encountering tasks on gases, and perhaps science in general.

## **Procedure**

### **Sample**

The Norwegian school system is based on 13 years of compulsory schooling; that is, from kindergarten to the 13th grade, compared to the South African system of kindergarten to the 12th grade. For the purpose of comparison, Grade nine in Norway is equivalent to Grade eight in South Africa. Two small purposive samples consisting of 88 learners from each country were selected for this study; the South African students recruited from the Western Cape area, while the Norwegian students were recruited from the Bergen Municipality in Norway. For both samples, the following criteria had to be met: (1) the schools must be within the districts approved by the Department of Education in each country for the study; (2) the teachers must be willing to participate in the large-scale survey project known as Scientific and Technology Literacy Project (STLP) in South Africa; (3) they must be actively involved in the development (or adaptation process, in the case of Norway) of all the assessment instruments; (4) they must have been teaching science in Grade 8 or Grade 9 for at least five years; and (5) the school administrators and the circuit managers or supervisors must be supportive of the project. Although the two samples were not generally representative of the two countries (insofar as they were drawn from willing schools in particular geographic areas), they will, for the sake of simplicity, be referred to as South African and Norwegian. The intension is not to generalise beyond the schools, but to provide a platform for further studies in the area.

### **Instrumentation**

An instrument known as 'My Ideas of Gases' (MIOG) was developed to assess the students' understanding of gases and the underlying process skills. The initial draft of MIOG, consisting of 30 items, was pilot-tested and subjected to a series of revisions involving four experienced science educators and 19 science teachers before reaching its final form consisting of 18 items (see Ogunniyi, 1999). To obtain a high level of validity and reliability, MIOG was judged against three criteria: (1) the items must be based on the performance of specific cognitive tasks; (2) in as far as possible, the items must be situated within the students' everyday experiences; (3) students should be able to complete the instrument within 30 to 40 minutes of a normal lesson period. In addition, the final draft of MIOG was given to two experienced science educators in South Africa to rank the items on a scale of 1 to 5. In this regard, a poor item would be rated 1, a fairly good item 2, a good item 3, a very good item 4, and an excellent item 5. Their rating was then subjected to Spearman Rank Difference Formula. The inter-rater coefficient for MIOG stood at 0.90, while its reliability using the Kuder-Richardson 21 formula as modified by Ebel (1979) was 0.94; thus suggesting an instrument with a high face, content, construct validity as well as reliability (Ogunniyi, 1992).

The list of question descriptors shown in Table 1 was used in writing questions to assess some of the process skills related to the assessment framework. The sub-categories in Table 1 correspond as much as possible to those specifically related to the process skills covered by MIOG items. This implies that an item may involve the use of one or more element in a given sub-category, depending on the cognitive demand of such an item. For instance, while some items require only the recognition of an event or assigning the appropriate meaning to it, others require interpretation of graphics, and others require justification or additional explanation. After various trial runs among eight judges (four in Norway and four in South Africa), consensus was reached regarding the categorisation of the process skills of the Assessment Framework. For pragmatic reasons and to reduce cases of overlap, the original six categories were divided into two equal categories of nine items each. The classification/conception process skills category is in accordance with Bruner's (1960) notion of knowledge restructuring. In Bruner's view, conceptualisation is a representation of reality, e.g. objects or events with identical characteristics. To him, conceptualisation is synonymous to categorisation. Hence, a bird is a

category of animals with feathers, beak, wings, two legs, two eyes, etc.; an acid is a class of aqueous solutions with bitter taste, turns litmus red and reacts with bases or alkalis to form salts. The application/decision-making process skills are construed here to give the ability to mobilise both basic and higher-order cognitive skills to perform a given task (Aikenhead, 1985). It is also an individual's ability to use scientific information or concepts creatively to tackle an unfamiliar problem and make an informed decision.

The nine items on the MIOG demanding the use of the basic or classification-conception process skills of the assessment framework are: 1.1, 1.2, 1.3, 2, 3, 5.1, 5.2, 6 and 8, while the other nine demanding the use of high-order or application-decision-making process skills are: 3.1, 4.1, 4.2, 7.1, 7.2, 7.3, 9.1, 9.2 and 9.3. Disparities in the categorisation of the process skills on any item were later resolved through argumentation by a panel of four science educators before consensus was reached. This entailed justifying why a particular process skill was deemed necessary by a judge in the performance of a particular task. However, in all these endeavours, the authors were well aware that it was theoretically impossible to place any category or sub-category of cognitive processes into watertight compartments.

As indicated earlier, and as reiterated by Schofield (1989), the analysis used in this study is based on the assumption that it is impossible to separate process skills from the content that propels them into action, so to speak. Each item on the MIOG was assigned specific marks depending on its complexity in terms of the cognitive skills required to perform the task called for by the item. Hence, giving a correct answer without justification, where required, received only half a mark. Also, the markers used the assessment framework as the basis for allocating the scores for each item. The scores obtained were then calculated as means, standard deviations, t- and F-ratios. Also, for ease of comparison, the mean scores were converted into percentages as a direct comparison of one mean score with another, or stating that one mean score is higher or lower than another without considering the sensitivity of this statistic to the impact of extreme scores in a distribution is statistically fraught with difficulties (Ogunniyi, 1984: 57).

**Table 1: The assessment framework**

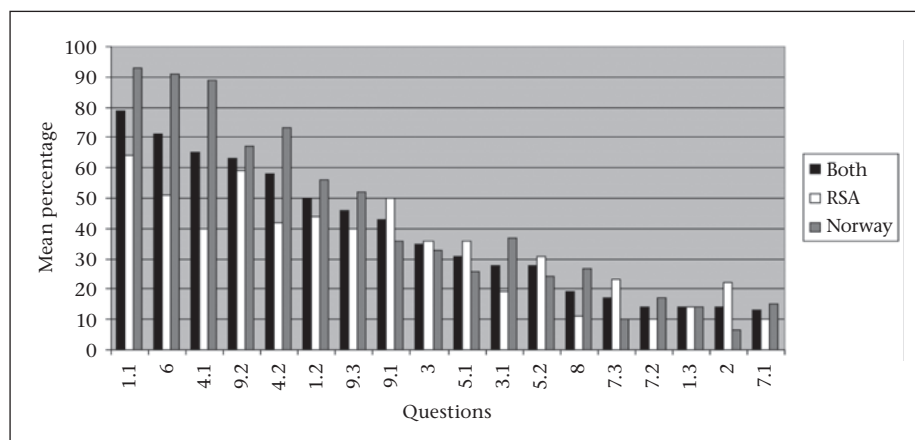
Category	Sub-categories
1. Classification/ conceptualisation (Basic process skills)	<ul style="list-style-type: none"><li>• Recall of facts, concepts or principles.</li><li>• Correct interpretation of graphics.</li><li>• Transforming data from one form to another, e.g. representing information as graphs, tables or charts.</li><li>• Using appropriate concepts, symbols and conventions or assigning valid meanings to scientific facts.</li><li>• Recognising and using scientific concepts to group phenomena.</li></ul>
2. Application/ decision-making (Higher-order process skills)	<ul style="list-style-type: none"><li>• Using presented information to predict phenomena.</li><li>• Applying scientific concepts to solve problems innovatively.</li><li>• Judging the applicability of information to a given problem or task.</li><li>• Generating valid alternative hypotheses.</li><li>• Using scientific information in making valid or informed decisions.</li></ul>

## **Results and discussion**

Figure 1 summarises the performance of the two groups of students on the MIOG, with an emphasis on the average of the two countries in question. The students appear to demonstrate a wide range of knowledge and process skills in performing cognitive tasks on gases. The South African students' scores range between 10% and 64%, while the Norwegian students' scores range between 6.5% and 93%. Overall, the students in this study scored 38% on average. This is in accordance with earlier findings in the large-scale survey done by this research group (Mikalsen, 2005; Mikalsen and Ogunniyi, 2005; Ogunniyi, 1996, 1999; Ogunniyi and Mikalsen, 2003; Ogunniyi and Mikalsen, 2004). The average scores have been between 32% and 38%, with some variation between the two countries. It has also been found that the students in both countries find the same questions to be either easy or difficult to respond to. It might therefore be that the challenges lie in the tasks rather than the contextual differences. However, this stance needs to be qualified in that the students' cognitive skills are the product of their socio-cultural environment. All that can be said is that the similarity warrants a closer investigation. Not surprisingly, tasks connected to the students' everyday lives seem to receive a higher score rate, while tasks connected to theory are more difficult for the students.

This suggests that authors of textbooks should put efforts into the task of using examples related to students' everyday experiences. In a recent study involving junior and senior secondary students in Norway (Mikalsen, 2005), it was found that context-based tasks increased the score rate at the senior level in the same manner as at the junior level, even if the score rate for the senior level was far over the score rate for the junior level. In that study, a pattern of high-performing and low-performing students was found, even if the average score was nearly double. The study here is concerned with determining the nature of knowledge and process skills demonstrated by the students to perform a given task.

**Figure 1: Students' performance on the MIOG in terms of process skills**



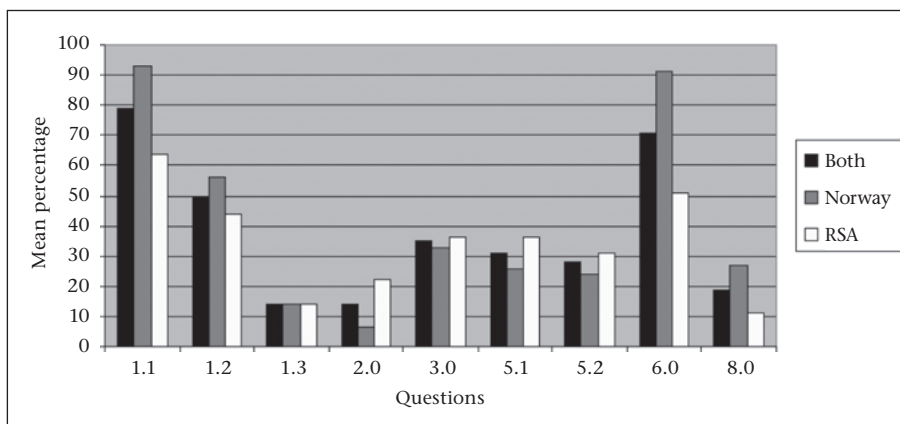
**Category 1: Basic process order skills**

Figure 2 summarises the mean scores for all the items in Category 1. Question 1.1 deals with the four most important gases (oxygen, hydrogen, nitrogen and carbon dioxide) found in the earth's atmosphere, and asks which of these gases is needed to keep a match burning. This item essentially requires the use of classification-conception process skills in terms of recall of knowledge or conceptions of properties of gases. Overall, Q1.1 was answered by an average of 79% of all students and was by far the easiest question for both Norwegian and South African students (see Figure 2). The question requires recall of facts or concepts. The same type of process skills are required to answer Q6, asking students to explain why a burning candle covered with a gas jar gets extinguished after a few

## *Knowledge and Process Skills Used to Perform Cognitive Tasks on Gases*

seconds. Q6 receives valid answers from 91% and 51% of the Norwegian and South African students, respectively. Also Q1.2, requiring the same sort of process skills and asking the students to name the gas that makes a popping sound when it is set alight, has received lower valid responses; i.e. 56% and 44% for the Norwegian and South African students, respectively. These three questions are the questions belonging to Category 1 with the highest answer rate. Q1.3 and Q8 are the two questions in the basic skills category that caused the most trouble. Q1.3 simply asks which is the most common gas in the atmosphere, and only 14% of the students in both countries could recall which gas is the most common in the atmosphere. The explanation for the low mean score could be because the students have not been exposed to the concept in class. Q8 deals with two statements about breathing: (1) we breathe in air and breathe out air; (2) we breathe in oxygen and breathe out carbon dioxide. The students have to decide which of the statements is more correct. The question requires recall of facts, and also that the students use appropriate concept. On the average, only 19% of the students could answer Q8.

**Figure 2: Students' performance on basic process skills**



The discussion, will therefore, be based on some questions in each category of the assessment framework. Appendix 1 summarises all the items on the MIOG and the expected responses in parenthesis.

### **Category 2: Higher-order process skills**

Figure 3 summarises the mean scores for all the items in Category 2. Six of the items will be looked into; Q4.1, Q4.2 and Q9.2 are the questions with the highest score rate in Category 2, and Q7.1, Q7.2 and Q7.3 are the questions with the lowest mean score in this category. Q4 deals with fizzy cooldrink. Q4.1 asks for an explanation for why the word 'fizzy' is used to describe the cooldrink, and Q4.2 asks what will happen to the cooldrink when it goes flat. Both questions were well answered, with an average score of 65% and 58% for the students in the two countries, respectively. To answer Q4.1, the students were required to make use of application/decision-making process skills, while on Q4.2 they were additionally required to use presented information to predict phenomena. Q9 gives a scenario of a cold winter night when a girl is making a coal fire inside the house. The next morning her friends find her lying unconscious on the floor. In three sub-questions the students are asked to solve some tasks. Q9.2 asks what the first thing is her friends should have done. The answer rate on Q9.2 is on average 63%. To give a correct answer to this question, students needed to apply most of the sub-groups under Category 2 – that is, use information to predict phenomena, apply scientific concepts to solve problems innovatively, judge the applicability of information to a given problem or task, and, finally, use scientific information in making a valid or informed decision.

The three sub-questions under Q7 have the lowest responses in Category 2. Q7 deals with the concept of combustion and is given as the word-equation for burning a fuel. Q7.1 asks why is it wrong to say that the fuel is used up during combustion. This question had the lowest response of all questions of the MIOG, with an average score of 13%. Roughly the same score (14%) was obtained by the students on Q7.2, which asked where the water and carbon dioxide come from in the equation.

Some alternative explanations given by students on Q7.2 include:

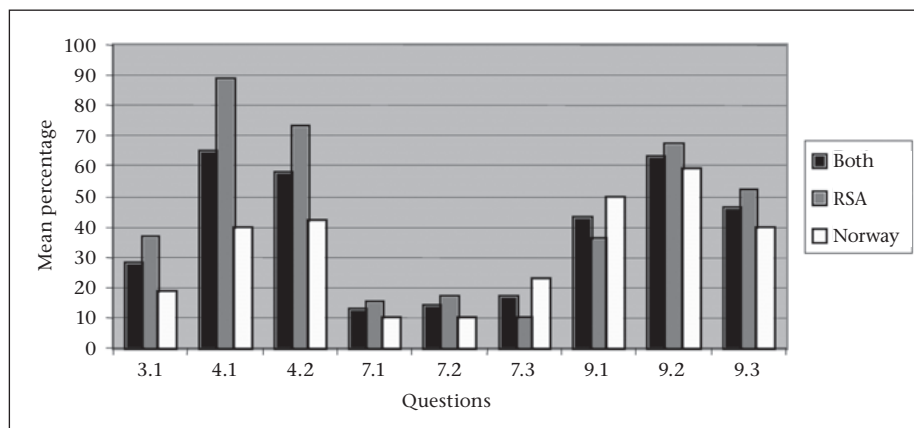
#### **South African students:**

- Atmosphere
- In electricity
- From above or the rain
- Underground
- Sky
- Oxygen

#### **Norwegian students:**

- From the oxygen
- Oxygen consists of carbon dioxide and water
- The water comes from the evaporation
- It disappears/goes up and water-vapour falls down as rain and carbon dioxide remains a gas
- From the clouds
- The water comes from CO<sub>2</sub>

**Figure 3: Students' performance on higher-order process skills**



The explanations given to Q7.2 seem to indicate that the students respond without taking the context the questions belong to into account (the context in this question is understood as what is happening when fuel burns). The responses are connected to one of the components of the equation, e.g. the responses 'From above or the rain', 'Underground', 'Sky', 'The water comes from the evaporation', and 'From the clouds', are referring to 'water'. All these statements could be correct answers to the question: 'Where does the water come from?', but none of them are responding adequately to the question raised. The response: 'Oxygen consists of carbon dioxide and water' is neither a correct answer to Q7.2 nor to any other question that could be raised since it is an incorrect statement. Could the explanation for students' actions be that the students are not reading the questions properly; they skim it and start answering immediately without making up their minds on what the questions is about? If that is a valid suggestion, could we find the reasons to be firstly that teachers sometimes push the students to work faster rather than instructing them on proper reading, and secondly that the curriculum is too heavy, forcing teachers to push students all the time? Q7.3, asking where the energy shown in the equation is coming from, was also poorly answered, with an average score of 17%. The low scoring rate on questions 7.1, 7.2 and 7.3 are probably due to the demand of higher-order process skills, such as applying scientific concepts to solve problems innovatively, judging the applicability of information to a given problem or task, and using scientific information in making valid

or informed decisions.

The low score in this study is in accordance with earlier findings in the large-scale survey done by this research group (e.g. Mikalsen, 2005; Mikalsen and Ogunniyi, 2005; Ogunniyi, 1996, 1999; Ogunniyi and Mikalsen, 2003; Ogunniyi and Mikalsen, 2004). The average scores were between 32% and 38%, with some variation between the two countries. Also, as indicated earlier, students in both countries find the same questions to be either easy or difficult to respond to. This pattern of performance is probably an indication of a mismatch between the curriculum content and the students' readiness. On the other hand, it may well be a reflection of poor instruction. Whatever the case, it is most probable that such deficits in the students' understanding will continue to be a handicap in their further studies of science, unless ameliorated on time.

## **Conclusion**

An implication of the low score obtained by these students in the MIOG is that unless they improve their performance, they will not be able to perform well in the matriculation examinations in three to four years time or in international studies. In other words, unless some deliberate intervention has been carried out to ameliorate their present level of misconceptions on the topic, they are likely to repeat their present underachievement. Students' understanding of, or predisposition towards, the study of school science is to a large extent conditioned by their prior or existing knowledge. In line with Ausubel's (1970) conundrum, it is better to determine the knowledge of a given phenomenon currently held by students before taking them further.

The wider curricular, instructional and research implications of the conclusion above seem obvious. In light of the poor performance of the majority of the subjects of this study on the topic of gases, how compatible are the present Grade 8 and 9 science curricula in South Africa and Norway with the cognitive readiness of the students? Also, in view of the fact that the MIOG was implemented after the topic had been taught in class, what sort of teaching had been done? It was suggested in the introduction that a critical feature of science is the quest to provide viable explanations to various phenomena. If research is consistently suggesting that this is an area where science instruction is failing, and where more research is needed to attain a better instructional practice, then it seems reasonable to accord the matter more scholarly attention. Certainly, a situation where

the majority of the school population is neither able to answer high-order questions nor display critical process skills should be of grave concern – not only for the teachers of these subjects, curriculum developers and science educators in Norway and South Africa, but also to stakeholders in other countries where a similar problem exists. A follow-up interview might provide further insight to this puzzle.

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## Appendix 1: Items of the MIOG

(Sketches, diagrams and drawings to Q4, Q5, Q6 and Q7 are omitted in this questionnaire. Accepted answers are given in brackets behind the questions.)

- 1.1 Which gas is needed to keep a match burning? (Oxygen)
- 1.2 Which gas makes a pop sound when it is set alight? (Hydrogen)
- 1.3 Which of these gases is most common in the atmosphere? (Nitrogen)
2. Your teacher forgot to replace the lid on the bottle of clear limewater that is used in the test of carbon dioxide. A day later the clear limewater became milky. Explain what caused the limewater to turn milky. (CO<sub>2</sub> in air reacted with the limewater)
3. A classmate does not believe that some gases are **soluble** in water. What do you understand by the word **soluble**? (Dissolves in water)
- 3.1 How does the fact that fish live in water prove your friend is wrong? (Fish need/use O<sub>2</sub> which is dissolved in water)
4. A fizzy cooldrink that has been left open will go 'flat'.
  - 4.1 Why is the word 'fizzy' used to describe the cooldrink? (Presence of gas bubbles)
  - 4.2 Explain what happens to the cooldrink when it goes flat. (The gas escapes)
5. Hydrogen is a light gas that can be used to lift airships such as the one shown in the picture. Unfortunately hydrogen is a dangerous gas since it burns easily when ignited (burned) in the presence of oxygen. In 1937 the airship Hindenberg collided with electricity lines and caught fire. The word equation for hydrogen burning in air is:

Hydrogen + oxygen → water

  - 5.1 Name the reactants in this reaction. (Hydrogen and Oxygen)
  - 5.2 Name the product. (Water)
6. Combustion is another name for burning. A jar is placed over a burning candle, after a while the candle goes out. Explain why this happens. ('The O<sub>2</sub> is used up', that is: O<sub>2</sub> is converted to CO<sub>2</sub>)
7. The word equation for the combustion (burning) of a fuel such as gas is:

Fuel + oxygen → carbon dioxide + water + energy

Why is it wrong to say that the fuel is 'used up' during combustion? (It changes to other substances)  
Where does the water and carbon dioxide come from? (From the fuel and the oxygen)

- Where does the energy come from? (From the fuel)*
8. *Whose statement is more correct? Explain your answer.*  
*Paul: We breathe in air and we breathe out air*  
*Nandi: We breathe in oxygen and we breathe out carbon dioxide (Paul: Air contains many gases. Most simply move in and out.)*
9. *On a cold winter night Thandi made a coal fire in an old tin and placed it inside her home. When her friends came to visit the next morning they found Thandi lying unconscious on the floor. They also found the windows closed and the coal fire had gone out.*
- 9.1 *Explain why Thandi became unconscious. (Lack of O<sub>2</sub> and too much CO<sub>2</sub>).*
- 9.2 *What is the first thing Thandis' friends should have done after they found her unconscious? (Open windows)*
- 9.3 *What advice would you give to people who sleep where a fire is burning? (Open windows/good ventilation)*

# 14. *Mathematics Teacher Practices in Ugandan Secondary Schools*

Charles Opolot-Okurut, Cyril Julie,  
Øyvind Mikalsen and Silas Oluka

## **Abstract**

This chapter reports from an empirical study of mathematics teacher practices in high-performing (HP) and low-performing (LP) secondary schools in three districts of central Uganda. Differences and similarities of teacher practices in the HP and LP schools are compared. The analysis reveals differences and similarities with respect to: (1) the instructional resources; (2) teaching arrangement patterns; (3) student diagnosis patterns; and (4) the provision of additional teaching sessions. The findings are consistent with the global picture of differences in achievement according to socio-economic status of schools.

## **Introduction**

At the international level, there are current efforts to reform education. Educators in most countries are facing a number of educational challenges and they are grappling with initiating and implementing change in education. Issues that are prominent in this regard include: 'innovative teaching strategies; various measures to improve ... the quality of teachers; greater attention to 'constructivist'-inspired forms of teaching and learning; and the advent and impact of new technologies on classroom practices' (Hargreaves *et al.*, 1998: 2). Teachers are key members of the education community and are agents in the teaching and learning process in classrooms as well as in the education enterprise in general

– making them important agents for change in classroom practices. In Uganda, not much attention is paid to what teachers do and how they go about their work in classrooms. This relates to the question of teacher practice. Teacher mathematical practice refers to the decisions teachers make and the actions they take in the process of teaching mathematics in order to realise certain objectives. Bodin and Capponi (1996) have argued that sound knowledge of dominant teacher practices and the ways any secondary and compounding practices function is a prerequisite for improving mathematics teaching. The issue reflected on in this study was inspired by the contention that ‘knowledge of current practice is a necessary first step in transferring practices developed in research to the wider educational community’ (Groves and Doig, 1998: 17), and by the argument that ‘case studies documenting and analysing contemporary school practices need to be built’ (Hatton, 1999: 236).

An obvious fact is that teacher actions have a bearing on students’ learning of mathematics. Tanner and Jones (1999: 256) link teacher practices to effectiveness when they assert that ‘to be effective a teacher must evaluate the given curriculum and then select or emphasise certain aspects of content, or create materials that will be appropriate within a particular classroom situation’ as part of his/her practice. Furthermore, the pedagogical strategies that teachers use in their classrooms depend on the perspective that they bring to teaching and learning. Etchberger and Shaw (1992) highlight this issue by raising a pertinent question: What do (mathematics) teachers preoccupy themselves with in classrooms, is it to enable students to solve problems or to show them how to solve problems? Do the practices that teachers employ in their classrooms enable students to apply learned concepts, or do they merely learn to know about mathematical concepts, skills and procedures?

Teacher practices in schools have been studied in the sub-Saharan region by researchers such as Ottevanger, Leliveld and Clegg (2003) and Nkhoma (2002).

Teachers are diverse. For instance, in a year-long study, Aubrey (1996), through observation and interviews, investigated the influence of teachers’ pedagogical subject knowledge on the content and processes of mathematical instruction in reception classrooms in the UK. Aubrey (1996: 193) found that ‘practice among the different teachers, as well as the practice of one teacher across lessons, varied in terms of mathematical content introduced, its representation in tasks, in the support offered

and, consequently, in the quality of instruction provided'. Furthermore, research on teaching and learning mathematics has shown that teachers' instructional practices are shaped by, among other factors, their knowledge of mathematics content and pedagogy (Ball, 1991; Fennema and Franke, 1992; Franke, Fennema and Carpenter, 1997), and their expectations (Jussim *et al.*, 1998). Cuban (2001: 165), after studying how teachers taught over a period of nearly a century, concluded that 'knowing how teachers have taught provides a modest basis for understanding what they face daily in classrooms today and how far pedagogy can be altered, given the existing organisational structure'.

Usually, little information of the 'private life' inside the classroom leaks to the outside world, and yet there are many interested parties who want to know what goes on there. Most of the time, mathematics teachers' teaching practices remain an unknown quantity. The general public tries to infer what happens inside classrooms from students' academic outcomes, which are made public through examination results. Bodin and Capponi (1996) have argued that sound knowledge of dominant classroom practices and of how any minor compounding practices function are prerequisite for improving mathematics teaching. Similarly, Groves and Doig (1998: 17) have maintained that the 'knowledge of current practice is a necessary first step in transferring practices developed in (or identified through) research to the wider educational community'.

The above narrative brings to the fore some factors that impact on teacher classroom practices and the value that knowledge about their practices might have on improving classroom practices to impact positively on student learning.

### **Dilemmas of school provision in Uganda**

Within the Ugandan education system there are some similarities and variations in the educational provisions and facilities that are offered. Disparities exist between schools, between teachers and between students. To some extent, these disparities are manifested in the 'quality labels' that the general public often gives to schools. A school quality label or 'school type' refers to how the general public names schools that produce satisfactory or unsatisfactory examination results. A school quality label appears to be a product of a combined effort of administrators, teachers and the students in the school. The public continuously ask why some schools perform better than others and the general opinion is that some

students receive better quality education than others. Consequently, educators, policy-makers, researchers and the public are interested to know how secondary school teachers teach their students and what actually goes on in the classroom. In line with this, disturbing questions arise; such as: What is it that teachers actually do in their classrooms? Driven by this popular enquiry, this chapter reports on what teachers in HP and LP schools say about their instructional practices and schools.

## **Methodology**

The study followed a qualitative research approach. For the purpose of the study, data were collected through non-participant observation, interviews and audio-recording.

The focus was on secondary school mathematics teachers. The schools for the study were selected from the Uganda Certificate of Education (UCE) national mathematics examinations results for schools for the years 1998 and 1999, accessed via the Uganda National Examinations Board (UNEB). The secondary schools' average mathematics mark over the two-year period was computed and schools were ranked based on the mathematics average mark of the candidates in each school. The average marks for the schools ranged from 2.4% to 57.4%. The schools were divided into three categories: (1) schools whose average mark fell in the bottom 27% of the range; (2) schools whose average mark fell in the middle 46% of the range; and (3) schools whose average mark fell in the top 27% of the range. The 27% cut-off value was chosen because it 'provide[d] the best compromise between two desirable but inconsistent aims: (1) to make the extreme groups as large as possible and (2) to make the extreme groups as different as possible' (Ebel, 1979: 260). The schools in the bottom 27%, were labelled as low-performing (LP) and those in the top 27%-group were labelled as high-performing (HP). The HP and the LP schools were used in the study. The HP and LP schools were identified, located and requested to participate in the study. For logistical reasons, only schools that were geographically located in three districts of central Uganda were used for the study.

The secondary schools identified as HP or LP schools were given code numbers. In all, a total of nine schools were used for the study – five HP schools and four LP schools were randomly selected from the code numbers. These schools had different characteristics ranging from single-sex and mixed boarding schools to mixed day school. Four schools from

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the nine identified (two HP and two LP schools) were randomly selected. The HP schools were given HP1 and HP2 as pseudonyms, while the LP schools were given LP1 and LP2 as pseudonyms. The pseudonyms were used to conceal identity of the institutions and the participants in order to conform to the ethical issues and considerations of the research process.

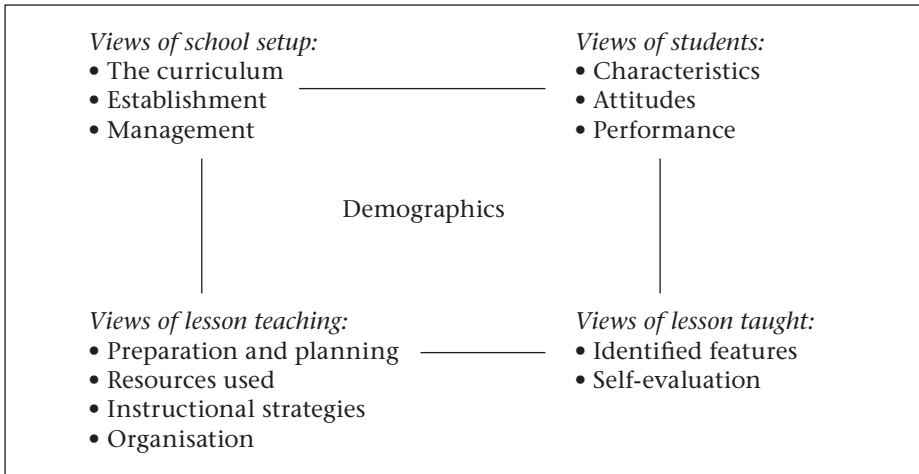
A small purposeful and theoretical sample (Merriam, 1998; Patton, 1990) of four teachers (two from HP schools and two from LP schools) participated. The teachers: (1) were professionally qualified to teach mathematics; (2) had more than three years of teaching experience; (3) taught in a senior three (S3 or Grade 9) mathematics class in the school; and (4) were willing to participate in the study. All the teachers turned out to be male due to the negligible number of female mathematics teachers in the schools. The four teachers were given pseudonyms T1 and T2 in the HP1 and HP2 schools, respectively, and T3 and T4 in the LP1 and LP2-schools, respectively. All the teachers were graduate mathematics teachers with B.Sc. Ed or B.Ed. degrees. They had teaching experience ranging between six and 17 years. Both T3 and T4 were heads of mathematics departments in their schools and had more teaching experience than T1 and T2.

Two study instruments were used for the study: The Lesson Observation Protocol (LOP) and the Teacher Interview Guide (TIG). The LOP instrument was intended to capture the events in the classroom as the teachers conducted lessons. It had a semi-structured format that included columns for the time, the lesson-development, the teacher's and students' activities, and the comments. Non-participant observation was used in this study, such that any events – defined as 'any behaviour, interaction, or activity that occurs within the perceptual field of the observer while in the classroom and captures his or her attention' (Anderson and Burns, 1989: 135) – observed were determined and recorded as they unfolded.

The interview information-gathering exercise followed soon after the observations. Interviews were deemed most appropriate to obtain data that were treated as experiences or 'actively constructed "narratives"-involving activities' (Silverman, 2001: 113). The Teacher Interview Guide (TIG) was used for interviewing. The TIG was a semi-structured guide that contained 17 key questions, which were explored with each teacher-interviewee. Qualitative interviewing – construed as a 'conversation with a purpose' (Burgess, 1984: 102) – was used because the researcher wanted to determine what is 'in and on someone else's mind' (Patton, 1990: 278). The

TIG was divided into five themes that focused on the views on the school setup, the views of students, the views of lesson teaching, the views on the lesson taught and demographic information (as shown in Figure1). The TIG required the teacher to explain some of the actions observed during the lesson and to clarify inconsistency or striking or unusual actions that were observed.

**Figure 1: Themes covered in the teacher interview guide**



A researcher and a research assistant conducted each lesson observation. Each observer recorded the observations for a particular observation session. The lessons were also audio-recorded as they progressed.

The participating teachers taught lessons they had prepared according to their school timetable. This allowed the classroom environments to operate in their normal setting. The lessons ranged from 40 to 80 minutes in length. The LOP was used to capture in detail what the teacher was doing or saying in class, and an appropriate description was constructed in the comments column. Each lesson observation was immediately followed by post-instruction interviews.

The observers shared their notes after observation to arrive at an inter-observer agreement that was then recorded for the particular lesson observed. A third trained research assistant, using only the audio-recordings, provided a further control to check that the lessons were systematically observed.

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The interviews were conducted with teachers immediately after the lesson presentation and were tape-recorded. Teachers were, for instance, asked to explain some of the actions observed during the lesson or to clarify what was observed as inconsistent or striking/unusual actions.

A quasi-grounded theory approach was followed to analyse the data and distinguish the processes that explain what was happening in a social setting (Strauss and Corbin, 1990). The audio-taped data were transcribed and coded using the Atlas/ti qualitative data analysis programme. Open coding was used to form initial categories of information about what the participants said by segmenting the data. Categories were construed as units of information made from events, occurrences and instances (Creswell, 1998; Strauss and Corbin, 1990). Next, similarly coded events, statements that tried to capture the same meaning, were grouped as categories. The emergent categories were discussed with colleagues and were refined. The categories in each interview were looked at and compared for similarities and differences. The overall phenomena that best described the experiences of the participants were identified. The analysis was analogous to the constant comparative method (Merriam, 1998; Miles and Huberman, 1994; Strauss and Corbin, 1990).

### **Findings**

The findings of this study indicate that the practices of teachers in Ugandan secondary schools are impacted differently by: (1) instructional resources, (2) the teaching arrangement, and (3) the diagnosis of student difficulties. Furthermore there is differentiation with respect to the provision of additional teaching sessions.

Differences in teacher practices included the quality and quantity of instructional resources and teaching arrangement.

### **Instructional resources**

In the HP schools the instructional resources included textbooks, supplementary materials and equipment, and the use of technology. In the analysis of how instructional materials and resources were used, several ways of working were identified. First, the teachers in the HP schools used a wider variety of textbooks and instructional materials, which included personal- and Ministry of Education and Sports (MoES)-prescribed textbooks. Second, teachers in the HP schools used physical models such as teaching aids and locally available materials from the environment to

try to relate mathematics to a context. The local materials were particularly used for specific topics such as statistics and three-dimensional geometry. Third, teachers in the HP schools used past Uganda National Examinations Board (UNEB) examination-paper booklets and the school's past papers as a source for their exercises and problems. UNEB past-paper booklets are a collection of past examination questions covering several years that are produced by UNEB and sold to schools and interested individuals. Fourth, the use or application of technology entails the use of calculators and computers for teaching mathematics. Calculators were the main technology used in teaching mathematics. Teachers in HP schools had more calculators at their disposal (each student had one), but there were no computers available in the classrooms. The levels of economic status of the different schools, what Turmo (2002) has called *economic capital* or financial resources, are varied and determine the instructional resources at teachers' disposal in the schools.

The teachers in the LP schools had a shortage of resources to the extent that during mathematics lessons students hardly used any textbooks, which was in stark contrast to the situation in the HP schools. Usually the only available textbook was for the teacher. Although there was a shortage of textbooks at the LP schools, it was evident that the teachers carried, consulted and read different books to prepare teaching notes. This was at least the case in LP1, as T3 testified:

I normally carry my own books, for instance, and I use various textbooks. I use *School Mathematics* by Parr, I use *Essential Mathematics* for those in senior three, and then I have other textbooks, which I normally consult. So what I normally do is, I go home and read a chapter, I consult those books, prepare my lesson, then I use that as basis for teaching my lesson. (T3-INT – interview with Teacher 3)

In contrast to HP schools, there was limited use of technology in the classrooms in LP schools. Even though calculators were available in small quantities in each classroom, they were not extensively used. These findings are consistent with the results of other surveys (Dion *et al.*, 2001; Huang and Waxman, 1996) in that technology was not widely used in schools and classrooms in a developed country such as the USA. The findings in this study support those results. Some possible explanations

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for the limited use of calculators are that technology such as calculators are still expensive in Uganda for the average student. However, there was enthusiasm among the students in the LP schools to use calculators in addition to using logarithmic tables. The students' eagerness to use calculators challenged teachers to address problems using both logarithmic tables and the calculator, which forced the teachers to attend to different student needs. As T3 explained:

When I am doing a number, which involves calculations, I carry mathematical tables ... then other people [students] use calculators that means you have to cater for both interests. You give a concept where they can use a calculator; and they work it out, then you give these ones with mathematical tables, then you work with them and see what they come up with. (T3-INT)

In the same vein, T4 reported that students at LP2 'have calculators, they have logarithmic tables, and we have in stock enough logarithmic tables as printed materials to cover each per student'.

The use of models and teaching aids in the LP schools contrasted with what the teachers in the HP schools did. The teachers in the LP schools hardly used any teaching aids or models and essentially taught mathematical concepts theoretically.

Thirdly, in contrast to the teachers in the HP schools, the teachers in the LP schools did not use past UNEB papers for teaching, instead relied heavily on the school's past papers and textbook exercises.

### **Teaching arrangements**

Teaching was managed differently in the various schools. First, the HP schools had a larger teaching force of between six and 14 teachers and teachers were deployed in a vertical pattern. In the vertical teacher-deployment pattern teachers progress upwards with their group of students each year to the next class. The vertical teacher-deployment practice allows the teacher to become familiar with his/her students. This deployment pattern was dominant in the HP schools. For example, at HP2, T2 reported that:

In some other schools, there is a teacher called Maths teacher for S1, Maths teacher for S2, Maths teacher for S3 what we do is, you teach students from S1 up to S4, the same group from S1, you keep moving with them ...

We have a system whereby you pick a stream from senior one; when they go to senior two, you move with them; senior three you are with them; senior four, you are with them. (T2-INT)

Second, the teachers in the HP schools organised synchronised teaching. Synchronised instruction entails teachers sharing ideas with colleagues on topics content and their coverage, and they attempt to cover the same topics and content concurrently. These teachers planned to teach similar content at the same time. They prepared common schemes of work together and set common tests and examinations. They also re-ordered the topics in the textbooks and the syllabus to facilitate organised coverage. For example, according to T1, teachers at HP1 rearranged some topics in the textbooks and syllabus that were covered over several years (such as statistics) so as to offer it as coherent content and have it finished off in a coherent way in one year. T1 pointed out, for example, that with 'statistics normally, we want to complete everything. Finish all the statistics theory. So that when students come to senior four they will only be solving problems'. T1 placed emphasis on the re-ordering of topics, as was illustrated in the exchange between the researcher (R) and him in the following excerpt.

R: Is the statistics covered in S.2, S.3 and S.4 following the spiral approach?

T1: Oh ya. Statistics is in senior one, senior two, and three then four.

R: So how do you teach this particular topic?

T1: The statistics. Normally, we want to finish everything.

R: Ok, what do you mean?

T1: Finish everything. Finish all the problems. So that when it comes to senior four they will only be solving problems.

R: Uhm ... So you sort of bring up everything together? (T1-INT)

At the same time the re-ordering of topics was also used at school HP2, as highlighted by T2. T2 started with an expression of unhappiness about the way authors arranged topics in their textbooks. According to him, topics were arranged in a spiral order with some topics being dealt with at a higher level almost annually. He claimed that some teachers tended to follow the textbook page by page, but at his school teachers conveniently re-ordered the topics in the textbooks and syllabus to their convenience.

In contrast, the dominant teacher deployment pattern at LP schools was horizontal, in that teachers taught at a particular level (e.g. like S1, S2, S3

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or S4 classes) throughout the year. This teacher deployment pattern was sometimes also used in the HP schools. For example, T1 pointed out that any teacher could be moved to any class at the discretion of the head of department. As he explained:

Like if you teach ... if you are given 3B, you have to teach it until the end of the year; unless there is a problem, you have to teach for the whole year. And maybe you can continue with it or you may not. But in most cases teachers don't proceed with the class they have taught previously... [Researcher: Are teachers fixed to classes?] Not exactly, you may be changed. Maybe to senior one or to senior two, or you may continue with your students. (T1-INT)

Second, the teachers in the LP schools followed the textbooks as dictated by the textbook authors or as suggested in the teaching syllabus.

The findings signal that the pedagogical strategies used by teachers in Uganda are limited and driven by the desire to overcome the 'overloaded curriculum', and that the 'pressure to complete the syllabus [that] prevents teachers to use more cooperative strategies in teaching' (Ottevanger, Leliveld and Clegg, 2003: 3).

### **Similarity of diagnosis of student difficulties**

Teachers in HP schools identify students with learning difficulties through diagnostic testing and examining student achievement levels. Also, these teachers tested currently covered work using written and oral tests. For example, T2 claimed that he identified students 'who were not performing' according to his expectation as those with learning difficulties. At the same time, the students' work showed areas that were not understood and needed more attention. As T2 declared:

When I give a paper like at the end of the year, you find certain questions on difficult topics have been dodged ... But when the teachers are marking, they always discover problems where most students are not performing ... These are the areas we need now to go into in detail in the syllabus coverage. (T2-INT)

Secondly, teachers in HP schools used achievement levels to identify weak

students who needed help. They also used various methods and techniques to determine students' difficulties through identifying students' lack of understanding and/or misconceptions.

Similarly, like teachers in the HP schools, teachers in the LP schools used revision tests that covered previous work done. The teachers in the LP schools used the diagnostic approach of critically analysing students' work in order to identify students with difficulties in mathematics. For example, at LP1, teacher T3 expressed that he extended the diagnostic approach to testing, including previous years' as well as currently covered work. As a result, he was able to detect sources of student weakness from the gaps that they left as unanswered parts of questions. Meanwhile, teachers in the LP schools identified the topics that needed attention as those problems students did not attempt in the exercises.

### **Provision of additional teaching sessions**

Teachers in the HP schools organised additional teaching sessions outside official class time. The additional teaching sessions were organised at different times. The organisation of additional teaching sessions varied according to: (1) the time of contact; (2) the school policy statement on additional teaching; and (3) the goals of additional teaching. The additional teaching sessions involved availing students with more engagement time outside the official contact time to advance their learning. Teachers in HP schools used weekends and specially arranged times to conduct additional sessions. For example, at HP2, additional teaching sessions were conducted either after school, over lunch breaks or on the weekend. Additional teaching sessions served several functions and were organised for different reasons. For example, the arrangements and the organisation of additional teaching sessions at HP1 was to ensure that the students did not fall behind and to try to improve their understanding of what was taught. The teachers in HP schools used additional sessions to re-teach what was not clear and not understood. At HP2, the additional teaching served to provide extra work for students who experienced difficulties in certain topics. Additional teaching sessions were also organised in both the HP schools to try to cover untaught work in order to try to complete the content in the syllabus. Finally, in the HP schools the additional teaching sessions were a policy issue and teachers were remunerated for participating in teaching them.

Teachers in the LP schools used holiday time to teach additional sessions.

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T3, for example, stated that the school vacation was shortened 'by one week, to recover the first week which is always lost' due to poor attendance of students at the beginning of the term. The poor attendance was usually due to non-payment of fees. Furthermore, T4 indicated that they offered additional teaching sessions during free time or during periods that are created to try and cover uncompleted work:

What happens is we always create remedial lessons in free periods ... so that the work that is kept pending ... is normally compensated for during those remedial periods, which we create within term and at times during the holidays. (T4-INT)

In contrast, although additional sessions were similarly offered at the LP schools, they were not paid for (as is the case in the HP schools). The functions of additional teaching sessions at LP2 included covering uncompleted work. As teacher T4 stated: 'During those extra periods we are talking about, we catch-up [with unfinished work]'. 'Catching up' was taken to mean compensating for time that was lost by teaching uncompleted work at that time. Second, the teachers in LP schools organised additional teaching sessions to clarify or re-teach at a slower pace what students had covered but had not understood well.

### **Discussion**

The principal purpose of this study was to investigate the nature of teacher practices in secondary schools in Uganda. More specifically, this study addressed the question: What do mathematics teachers say about their practices in HP and LP schools?

First, teachers in the LP schools did most of the teaching from a single textbook as a content source, while teachers in the HP schools used several sources. This finding replicates Kiragu's findings in Kenya. Kiragu (1995) observed that the teaching of Standard six mathematics classes was predominantly characterised by: (1) the use of several examples from the textbook; (2) a lot of emphasis was placed on following routines established during the lesson to solve the assigned problems; and (3) students were not given the opportunity to do problems outside the textbook or even to discuss the solutions among themselves, or to explore various ways of arriving at a particular solution. This pattern of characteristics was more or less replicated by Wong (in Clarke, Clarke and Sullivan, 1996: 1211),

who claimed that most mathematics teachers taught in accordance with three things, namely: (1) the textbook; (2) the examination syllabus; and (3) past papers in public examinations.

Second, the findings show that there is a shortage of teaching and learning materials, mainly in the LP schools. Teachers in the HP schools had access to and used more instructional resources and materials and a greater variety of textbooks than their counterparts in the LP schools. This finding is consistent with the findings of the research on trends and challenges in instructional practices in different sub-Saharan countries. It is well documented that 'many of the country profiles emphasise the lack of adequate teaching and learning facilities, textbooks and pedagogical materials' coupled with their availability, supply, evaluation and selection (Ottevanger, Leliveld and Clegg, 2003: 3). The findings in this study echo the position of instructional materials in other sub-Saharan countries studied. For example, in South Africa it was reported that 'because of the lack of resources in many schools, the teacher is often the learners' only resource to learning' (Ottevanger, Leliveld and Clegg, 2003: 3). The teacher interviews and classroom observations indicated that textbooks are a primary determinant of what is taught in both HP and LP schools, although textbooks were in shorter supply in the LP schools. The data indicated that there were more instructional resources and materials in the HP schools than in the LP schools.

Third, this study found that teachers in HP schools were deployed in the vertical pattern, but the teachers in one LP school were deployed in the horizontal pattern. The differences in teacher deployment patterns may stem from the number of mathematics teachers in the school. In addition, the teachers in the HP schools re-ordered the syllabus and textbook topics for the logical convenience of teaching. They then taught synchronised lessons so that all the teachers taught the same content at the same time. The teachers in the LP schools taught topics following the textbook sequence. The topics in the textbooks that are used in the country follow a spiral approach to the topics (in that the topics recur year after year), but in the re-ordered arrangement the content of related work was conflated and taught over a shorter period. This was done to avoid losing track of the content and having to later re-teach it to refresh students' memories when the topic was picked up again. Furthermore, all the teachers in the HP schools structured their teaching according to the way topics appeared in final examination papers.

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The pattern of teaching in both types of schools allowed for the teachers to be in control of what was taught and when it was taught. This finding replicates the observable measures of teacher-centred instruction that Cuban (2001) advanced. The teachers in both types of schools probably teach in the same traditional way they were taught. This finding is at variance with the emphasis for teachers to adapt to learner-centred teaching (Evans, 2002; McCombs, 2003; Meece, 2003).

Fourth, another finding of this study was that the teachers applied their perceptions of students to guide their teaching. The teachers took into account what they considered to be their students' attitudes, their grades at the time of admission, the students' primary-school background, and the students' freedom to communicate. This finding is consistent with Thompson's (1992) finding that teacher practices are shaped by their beliefs and conceptions. This means that the teachers tried to adjust their teaching according to what they saw as students' needs and abilities, in a manner in which they perceived it. For example, the teachers in the LP schools believed that some of their students had negative attitudes towards mathematics that they attributed to poor primary-school academic background.

Fifth, the teachers supported conducting additional teaching sessions so as to: (1) re-teach work already covered in order to clarify what was not understood and not clear; (2) attend to individual student differences; and (3) review the work covered in earlier lessons, terms or years and catch up. In the HP schools the additional teaching sessions were conducted during preparatory time and during the breaks; whereas the LP-schools conducted the additional sessions during the holidays or early in the morning before school started. The preparatory time was convenient for the HP schools because they were boarding schools, and holidays were convenient for the LP schools because the students were usually from the local community around the school. In the HP schools the additional teaching sessions were an accepted part of school routine that was supported and encouraged by the school administration. The teachers were financially remunerated for additional teaching. In the LP schools, on the other hand, the additional teaching sessions, though apparently accepted by the school administrations, were not supported by additional remuneration. In the HP schools the main goal of the additional teaching was the maintenance of content coverage; whereas in the LP schools it was for catching up with uncompleted content. This indicates that there was either too much

syllabus content to complete or the time allocated to mathematics per week was not enough. These findings replicate the findings of Nkhoma (2002), who found that students in South African secondary schools attributed their success in mathematics to extra classes they were taught. The extra classes taught in South African schools are similar to additional teaching sessions that teachers in Uganda are using. Lauer *et al.* (2003) found that out-of-school strategies such as summer schools, after-school sessions, an extended day, before-school sessions, vacation sessions and Saturday schools were effective in assisting low-achieving students in reading and mathematics in the USA. Although these sessions provided more time for remediation and tutoring for low-achieving students, they could just as well be used for other students, as they are being used in Uganda.

## **Conclusion**

With respect to teacher practices in Ugandan secondary schools, it is clear that these practices are related to school type. It is evident that socio-economic differences among schools either enhance or constrain what teachers do and are capable of. The small sample size of schools and teachers used in this study obviously implies that the results cannot be generalised. The study does, however, provide leads that can be followed in order to shed further light on what is happening in classrooms in LP and HP Ugandan schools. A deeper and broader investigation on the effect of schools' socio-economic status on teacher practices with a view to improve practices in the schools is called for.

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# *15. The Participation and Contribution of Teachers in Zimbabwe Towards Their Own Professional Development*

Peter Kwaira, Stein Dankert Kolstø,  
Dirk Meerkotter and Meshach Ogunniyi

## **Abstract**

Historically, technical subjects in Zimbabwe have always been taught through the traditional approach where the teacher provides the facts and understandings, while the learner is the recipient. However, recent developments have culminated in 'Design and Technology' being adopted as an A-Level subject and as an approach at lower levels of the secondary school system. The advent of this change has meant the proliferation of new perspectives regarding instructional practice in technical education. The intensity of problems associated with differences in perspectives among practitioners has also resulted in the quest for continuous change and reform. This is especially the case now, at a time when educationalists the world over are advocating for the active participation of learners in educational activities. In most cases, educational reforms have been associated with the use of new materials. This is why, for some educators, it is pointless to discuss educational reform without referring to curriculum materials; thereby implying that materials are a vehicle for reform. In Zimbabwe, the nature of reform has meant the introduction of new syllabi, demanding appropriate instructional materials at various levels. Based on a pilot aspect of a major doctoral project pursued with the University of the Western Cape in South Africa between 2002 and 2006, the purpose of this chapter is to present the findings of the pilot study which looked at the design and development of

the Material Science course and the effect on the perceptions of teachers regarding instructional practice in Design and Technology.

## **Background and purpose of the chapter**

Most technical subject teachers in Zimbabwe have been accustomed to traditional methods of teaching where they present pupils with solutions to problem situations (Kwaira, 1998). All pupils would be required to do was follow instructions relating to laid-down procedures and measurements.

'Design and Technology' is a relatively new concept in Zimbabwe, both as a subject and as an approach in the teaching and learning of various technical subjects. Although, as an approach, the concept has been around since 1987, the subject side is a more recent development, introduced at A-Level in the year 2000. The subject is designed to accommodate students with a background in various O-Level technical subjects like woodwork, metalwork, building, and technical graphics. The materials were designed and developed based on ideas and principles adopted from the existing A-Level syllabus in Design and Technology. The purpose of this paper is to show the extent to which one group of teachers (2002/2003 B.Ed. intake) participated and contributed towards the design and development of the resource materials. The materials were subsequently going to be used with another group of teachers (2003/2004 B.Ed. intake) pursuing a Material Science course. The course is part of the Bachelor of Education degree curriculum in the Department of Technical Education at the University of Zimbabwe. In turn, the second group (2003/2004 intake) also played a role in the development of the proposed materials by participating in their implementation and evaluation.

The secondary research questions below were derived from a primary research question which is: To what extent could teachers participate and contribute towards the design and development of instructional resource materials designed for their professional development in Design and Technology? The challenge here was to actively involve teachers in the business of teacher education and training, since they are important stakeholders requiring staff development in order to teach Design and Technology at A-Level. The pilot study was designed to answer the following secondary research questions:

- What opinions do teachers hold regarding the level and adequacy of preparation during their initial teacher education and training to teach at the O-Level?

- What aspects of the proposed A-Level syllabus do teachers consider new and would like to see included in a course designed for them and aimed at their staff/professional development?
- What logistical problems and difficulties do teachers anticipate in the event that they teach Design and Technology at A-Level?
- What opinions do teachers hold regarding the suitability of the proposed specimen programme comprising the given instructional resource materials?

## **Theoretical considerations**

### **Design and Technology as a subject**

Before focusing on the design and development of the instructional materials, it was necessary to have an idea of how Design and Technology, both as a subject and as a concept, came to feature within the Zimbabwean curriculum. The emergence of Design and Technology education as an integral component of general education has become a significant international curriculum development of recent years (McCormick, Murphy and Hennessy, 1994). Its distinctive curriculum features are technological literacy and capability, and it highlights the importance of 'knowledge in action', of 'doing', as well as 'understanding' (McCormick, Murphy and Hennessy, 1994). In the Zimbabwean context, there has been adequate evidence indicating that the teaching of Design and Technology as a component of general education is an emergent, rather than an established practice. Many questions stand to be addressed and the subject is still a grey area. The study on which this chapter is based is organised on the basis of such questions; this with the general aim being to bring these challenges and possibilities (questions and possible answers) into focus.

However, given the multiplicity of these issues, the main project preceded by the pilot study on which this chapter is based had been focused on the professional development of teachers in relationship to their understanding of the subject and how it relates to other elements in the curriculum, especially science. Teacher preparation has been considered the main challenge. McCormick, Murphy and Hennessy (1994) assert that there is much uncertainty about how best to prepare teachers in Design and Technology and the assessment of technological competence offers formidable challenges to researchers and policy-makers alike. Attempts to develop and accommodate Design and Technology education within

different education systems would almost certainly make a meaningful contribution from a policy point of view and contribute towards building the relationship between this subject and other subjects in the curriculum – especially so in the case of science, which has now become a matter of academic, as well as practical, importance (McCormick, Murphy and Hennessy, 1994).

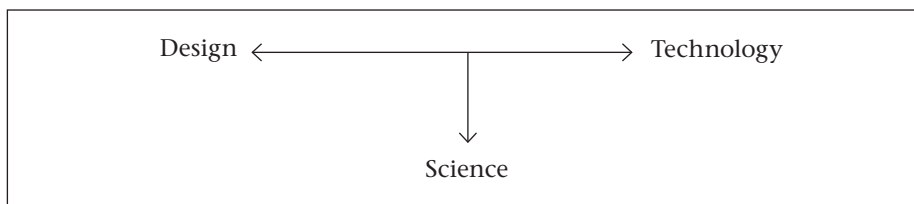
For the purpose of the investigation preceding this chapter, there was a need to define Design and Technology education. One had to be clear about the meanings of ‘design’ and ‘technology’ as separate entities. Among the authors, who have considered these two terms separately, are Fowler and Horsely (1988). Considering these terms in this manner is supported by Roberts and Zanker (1994: 5), who argue: ‘The view that “Technology” encompasses “Design” is quite incorrect and should be resisted.’ Roberts and Zanker (1994) encourage the demonstrating of an understanding of these terms separately, before explaining the link between the two concepts. Therefore, the intention here is to take heed of Roberts and Zanker’s advice for the sake of clarity in this chapter.

According to Fowler and Horsely (1988), ‘design’ is an activity, in which a wide range of experiences, knowledge and skills are used to find the best solutions to given problems, within certain constraints. Designing involves identifying and clarifying a problem, making a thoughtful response, and then creating and testing one’s solution. At this point, one can start to modify his/her solution, so that the process of designing begins again. Fowler and Horsely (1988) maintain that ‘design’ is a creative activity. One may often use known facts or solutions, but the way in which one combines these to solve a given problem requires creative thinking. Given this observation, it becomes evident that ‘design’ is far more than simply solving a problem. It involves the whole process of producing a solution, from conception to evaluation. This includes elements such as cost, appearance, styling, fashion and manufacture. Designers’ work features in almost every area of life; for example, product design, graphic design, interior design, engineering design and environmental design. Each area requires a different type of knowledge, but they all involve similar design activities (Fowler and Horsely, 1988).

While ‘design’ is an activity that has to do with problem-solving on the one hand; ‘technology’, on the other hand, has to do with the hardware or equipment used in problem-solving. One might be creative enough to think of a solution to a problem, but if there is no relevant equipment

to solving a given problem, the whole thinking process might be less valuable than it could have been. This is where one begins to consider the link between 'design' and 'technology'. The need for such a link is justified by the fact that we cannot have a complete solution to a problem without the two coming together. Another way of relating the two concepts is to consider their scientific orientation. For example, for one to engage in 'design' as an activity or as a process, that person has to be guided by scientific principles in his/her decision-making. Although it has to do with one's way of thinking generally (Kwaira, 1998), it is also evident that 'technology' becomes 'scientific' when principles, especially those relating to physics and chemistry, are used to develop the tools, equipment and materials employed in a problem-solving approach. Figure 1 shows a model illustrating how Design and Technology could be related to science.

**Figure 1: Relating Design and Technology to science\***



*\* Adapted from Kwaira (1998)*

Having looked at Design and Technology in the manner presented in Figure 1, the challenge involved in the task of trying to have such an orientation within the curriculum becomes clear. In various contexts, Design and Technology has been treated either as a separate subject within the curriculum, or as an approach through which traditional technical subjects like Metalwork and Woodwork would be taught. In Zimbabwe, the latter view has dominated our lower levels of secondary school education (Forms 1 to 4), while the former has been a more recent development aimed at the A-Level (Forms 5 to 6). However, despite a few areas of fundamental differences in terms of impact and impression within the curriculum, Design and Technology would still mean more or less the same thing when it comes to the kind of orientation that one ends up with after going through the theory involved in either the subject or the approach suggested here (Kwaira, 1998). For example, viewing it either

way, the underlying philosophy has to do with the promotion of creativity and problem-solving (Davies, 1996). This implies a situation where instead of presenting learners with solutions to problems, they are presented with problems for which they are expected to seek solutions through scientific investigation. The point being made here is that since this orientation features in both the approach and the subject of Design and Technology, what happens within the Woodwork and the Metalwork syllabi at O-Level would in this study be considered as a point of departure for the proposed A-Level syllabus.

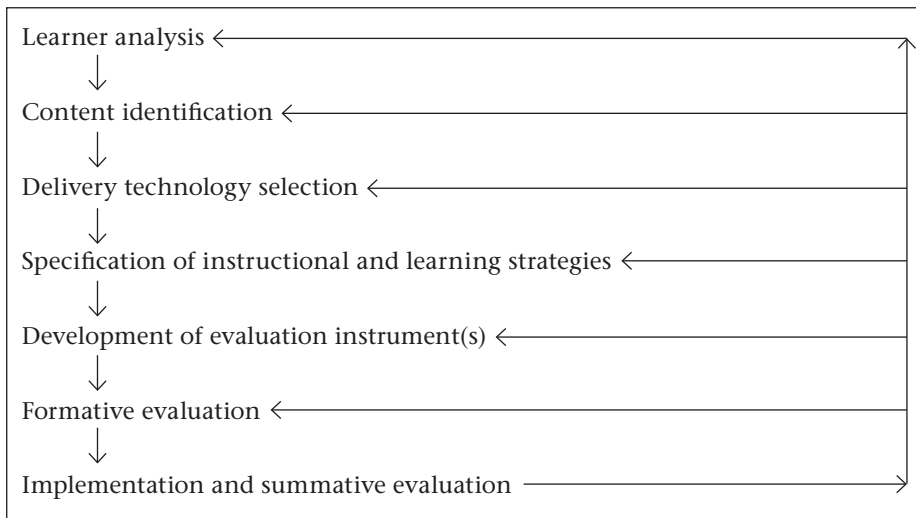
One of the most interesting findings in the literature is that the form and content of Design and Technology education differs among countries. Justifications for a range of approaches also vary (Jenkins, 1994). In some contexts, national economic concerns have impelled change. In others, the need to understand and control one of the most powerful influences on society today has been the primary motivation. Elsewhere, dissatisfaction with academicism and the recognition of the importance of skilful performance (capability) has brought Design and Technology to the fore (Jenkins, 1994). In several countries, international agencies like UNESCO and the OECD have supported, and continue to support, this curriculum innovation. According to Jenkins (1994), the work of many national and regional organisations concerned with Design and Technology education is supplemented by the activities of the World Council of Associations for Technology Education (WOCATE). As already observed, the central thrust of this innovation appears to be imbedded in the fact that Design and Technology education is about doing, not simply knowing. It is essentially about capability and knowledge in the context of action, rather than about understanding for its own sake. This is where such education is said to be about identifying a need, problem or opportunity; and designing, implementing and evaluating a practical response, which could range from systems to artefacts.

### **The instructional design model**

The study on which this chapter is based was concerned with the design and development of instructional materials meant for the professional development of teachers in Design and Technology, with specific reference to 'Material Science'. These materials were anchored on a model mainly adapted from Ally's (1997) version comprising seven developmental stages (see Figure 2). Nearly all the stages were covered during this pilot study,

except for the latter element in the last stage (summative evaluation), which then remained the focus of the main study. After implementation, the evaluation stage concentrated on the effect of the materials on the perceptions of teachers regarding instructional practice in Design and Technology.

**Figure 2: The instructional design model adopted for the purpose of this study\***



\* Source: Ally (1997)

It is interesting to note that Ally's model is a summary of two models, one by Romiszowski (1981) and the other by Dick and Carey (1996). For the purpose of the study leading to this chapter, it was necessary to determine areas of need through *learner analysis*. Initial teacher training became part of that analysis, in view of inadequacies resulting in teachers failing to teach Design and Technology at A-Level appropriately. The teachers were also required to help in the identification of the elements to be included in the resource package and then to participate in the evaluation of the materials for the sake of improvement where necessary. Following teachers' responses to a question, which involved the indication of anticipated logistical problems in the teaching and learning of Design and Technology at A-Level, *delivery technology* and *instructional/learning strategies* were identified.

## **Procedures**

### **Research design**

Since the study on which this chapter is based was meant to culminate in the design, development and evaluation of a prototype programme of instructional materials, it was approached mainly through developmental research. Methods of developmental research are not necessarily different from those associated with other research approaches. However, more than is the case in most other approaches, developmental research aims at making both practical and scientific contributions, involving both theoretical embedding and empirical testing of prototypes (Van den Akker, 1999).

According to Lijnse (2000), given the shortage of pedagogical knowledge in science education, progress in the teaching of science is possible provided one intensifies one's search for it through developmental research comprising 'design experiments' and/or 'teaching experiments'. In this chapter, apart from associating developmental research with the design and development of instructional materials, the materials were expected to have a positive impact or effect on the users (in this case teachers), thereby resulting in their professional growth and development. According to Van den Akker (1999), this type of research is often initiated for complex, innovative tasks, for which only very few validated principles are available to structure and support design and development activities. Although Lijnse and Van den Akker seem to differ slightly regarding the terminology for such an approach to research (the former referring to 'developmental research' and the latter referring to 'development research'), in essence they are basically talking of the same thing.

In terms of data collection, developmental research involves both quantitative and qualitative methods. All the data in the pilot study were collected by means of questionnaires. While a large amount of quantitative information was gathered through these questionnaires, the data lacked the necessary depth and detail, thereby necessitating follow-up interviews with a sub-sample of the respondents in order to provide meaningful additional data in order to make sense out of the data obtained through questionnaires. According to Patton (1990), data obtained through such qualitative methods often enriches the quantitative results. After the pilot study, several questions emerged, for example: What did respondents (teachers) really mean when they made specific reference to respective

questionnaire items? What additional information could respondents provide in order to clarify specific responses? How do the various dimensions of analysis fit together as a whole from the perspective of the respondents?

Typical activities in development or developmental research include: literature review; participatory research, usually involving the consultation of relevant experts (in this case, teachers); analysis of available promising examples for related purposes; and case studies of current practices to specify and better understand the needs and problems in intended user contexts (Van den Akker, 1999). At this point, it is important to note that case studies involving product and human resource development, as has happened in the main study commencing from the pilot study which led to this chapter, need to be conducted in several cycles – two, three, or more. Between the cycles one would critically reflect on what has happened, make the necessary adjustments and redesign the process (see Figure 2). The model illustrates that after implementation and evaluation, which is the last stage in a cycle, the process resumes going backwards, stage by stage. This cyclical process is meant to refine the thinking process behind the design and development of the materials and the pattern of arrows illustrates the cycles within the respective processes.

### **Sample selection**

In two groups of serving teachers in the Bachelor of Education degree programme of the Department of Technical Education at the University of Zimbabwe, the sample comprised 45 teachers drawn from the 2002/2003 intake and another 40 from the 2003/2004 intake. Enrolled in two programmes, the former group had 23 candidates enrolled for Wood Technology and Design and 22 registered for Metal Technology and Design, while the latter had 21 doing Wood Technology and Design and 19 following the Metal Technology and Design module. Unfortunately, during the last phases of the main project, the 2003/2004 group lost one member who passed away before completion of the programme.

Since these teachers were admitted from regions all over the country after an entrance examination, the two groups were reasonably representative samples of the population of technical subject teachers in the country. In a way, the whole selection process to the degree programme from short-listing, entrance examination and invitation, also suggested automatic randomisation in several respects, given the fact that students applied from

all over the country. Having mentioned this, the authors do not intend to generalise the outcomes of this investigation to the entire population.

### **Instrumentation and data collection**

Items were chosen in terms of importance according to their relevance and appropriateness in the context of Zimbabwe. To determine the levels of teachers' confidence concerning the teaching of certain themes selected from the O-Level Woodwork and Metalwork syllabi, their responses were analysed using a five-point Likert-like scale in the questionnaire. Teachers were asked to indicate, by ticking in the appropriate box, the extent to which they felt their initial teacher training had prepared them to handle specified aspects (relating to Design and Technology) when assisting pupils at O-Level.

In order to determine teachers' preference regarding new areas to be included in an in-service course or programme aimed at their professional development, they were provided with the proposed A-Level syllabus, which they studied and discussed in groups before responding. Issues of relevance and appropriateness within the Zimbabwean context implied by the five-point Likert-like scale as applied in this item, guided teachers in their choices regarding the degree of importance for each area. The respondents were also required to indicate the degree to which they agreed or disagreed with statements implying some anticipated logistical problems and/or difficulties.

Up to this stage of the research project, the questions mentioned above were addressed with the help of those 45 teachers belonging to the 2002/2003 intake of the Bachelor of Education degree programme in the Department of Technical Education at the University of Zimbabwe. Information, ideas and suggestions from this group led to the design and development of the instructional materials for the proposed specimen programme.

The second group of 40 teachers belonging to the 2003/2004 intake was presented with the draft materials of the specimen programme, which they studied unit by unit. After studying the materials, the teachers were required to evaluate the materials unit by unit, in the end dealing with the entire package. Evaluating the materials was meant to be formative in nature and it is believed that the process contributed to the further development and improvement of the materials.

The whole specimen package of resource materials was considered part of the research and development instruments; and teachers were given time to study and examine the materials for accuracy, reliability and validity before responding to further questions, which formed part of the 'formative evaluation'. It was hoped that the summative part of the evaluation would be achieved as part of the major study, where the intention was to determine the effect of the course on the 2003/2004 intake in terms of perceptions regarding instructional practice in Design and Technology.

According to the instructional design model in Figure 2, this type of evaluation is closely related to the issue of meaningful curriculum implementation. Since the 2002/2003 intake was actively involved in the development of the materials, it was suspected that they would have a vested interest in the materials and that it would be unlikely for them to be neutral in their judgement of the materials during evaluation. It was, therefore, deemed more appropriate to involve the 2003/2004 intake in order to obtain a more reliable view of the materials in terms of their suitability. Considered more neutral than the former, the second group was less likely to be biased in favour of the materials, and their contributions were therefore considered to be more constructive. However, since most of the members in the 2002/2003 intake had volunteered to be considered as resource persons, they were invited to do most of the teaching with the 2003/2004 group. They also assisted in the evaluation exercise by distributing the relevant questionnaires during the participatory data collection process referred to above.

## **Research findings**

### **Level of preparation during initial teacher education and training for Design and Technology**

According to the five-point Likert-type scale used, a mean score close to 1 would indicate that teachers felt their initial teacher education and training had 'not at all' prepared them to deal with particular aspects in terms of teaching at the O-Level. Two or close to 2 indicated that teachers felt they were 'not quite' prepared, and '3' indicated that they were 'undecided' in their feelings over an item. From '4' up to '5', teachers felt comfortable teaching a particular area ('well enough' and 'very well' prepared, respectively). Based on the analysis of the research data, it

became clear that teachers felt confident with their teaching of the theory of Design and Technology and Graphic Communication. With regard to the rest of the indicators of their level of confidence – from Material Science, Mechanisms and Motion, Structures, and Pneumatics Hydraulics – teachers were found not to be as comfortable as expected, since most of their responses ranged from ‘not at all’ prepared, and ‘not quite’ prepared, to a feeling of ‘indecision’.

### **Preferences of areas in terms of relevance and appropriateness in the Zimbabwean context**

Responses of the participants indicated that teachers had special preferences regarding what they wanted to see included in an in-service course designed for their professional development. In a way, the choices made here also appeared to be an indication of the areas teachers found inadequate in terms of preparation in initial teacher education and training programmes. The responses also indicated that there could indeed be a mismatch between teacher preparation and realities in schools.

The investigation also pointed to a view held by teachers which indicated that the following areas were important and they wanted to see them included in the proposed in-service programme: Materials Science and its related components, Structures, Mechanisms and Motion, Electricity and Electronics, Pneumatics and Hydraulics. The mentioned areas had mean scores ranging between 4.1 and 4.8.

### **Anticipated logistical problems and difficulties**

It was also found that the teachers viewed the lack of relevant literature, relevant equipment and materials (e.g. wood, metal and plastic), as well as a lack of support from teachers/instructors of other subjects to be among the most difficult problems they faced. Difficulties such as a lack of facilities, inadequate time allocation and an unsafe working environment were not viewed as problematic as the first-mentioned logistical problems.

### **The whole module**

Generally, the research shows a very positive picture of the programme as a whole, and that it was received very well. Responses during the evaluation of individual units made an extraordinary useful contribution towards the improvement of the whole module or course. However, despite all the positive responses on nearly all the items, item (b), which refers to the time

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allocation of 60 hours for the programme, gave a different picture where teachers revealed that they were not satisfied with the time allocated. Most teachers suggested more than 60 hours, with the majority (28 out of 39) proposing 120 hours. The rest suggested a time allocation of between 75 and 100 hours. Considering the amount of work in the module, one would perhaps be tempted to agree with those suggesting 120 hours.

With the exception of statement (b) referred to above, all the other statements participants had to respond to were met with a moderate to high level of approval by the participants. These statements were:

- This whole module or programme is very relevant for teaching Design and Technology at A-Level.
- The overall course aims have been clearly stated and were easy to follow.
- The overall course objectives have been clearly stated and were easy to follow.
- The overall course aim(s) has/have been adequately accommodated within the content.
- The overall course objectives have been adequately covered within the content.
- The course outline for this programme has been easy to follow.
- The module has been very well structured, right from the contents page.
- The sequence of various units has been very easy to follow.
- I think what I learnt in this course (programme) is going to be very useful in the event that I teach Design and Technology at A-Level.
- The various units in this module have been adequately introduced.
- The various units in this module have been adequately summarised.
- The practice and group activities have been generally relevant, appropriate and useful.
- The unit tests have been generally useful for revision purposes.
- The overall module test has given full coverage of the whole course.

### **Conclusions and implications of findings**

From the responses on research questions relating to this chapter, teachers appear to have contributed much towards the design and development of the proposed instructional materials, thereby contributing towards their professional development. By indicating areas of satisfaction and those of

need regarding the level of preparation during initial teacher education and training, teachers helped to establish a foundation for the proposed programme. According to the model in line with Figure 2 above, this is an example of the 'learner analysis' recommended by Romiszowski (1981), Dick and Carey (1996) and Ally (1997), who tend to agree on the view that in efforts to produce instructional materials for any programme, one should understand the needs of learners. Apart from identifying the needs of learners, addressing the first research question also meant 'content identification' of items for the instructional materials. When identifying content for a curriculum, one needs to include as many items as possible that are relevant to the needs of the learner and society at large (Ornstein and Hunkins, 1998). The active participation by student teachers in the design and development of their study materials is not really new. For example, Ornstein and Hunkins (1998) chronicle events of the 1960s when students started to take a more active role in their education as a spin-off from student movements perceiving the subject-centred curriculum as irrelevant to the prevailing social times. Students demanded a more progressive student-centred curriculum.

Closely related to the first, the second secondary research question was also about the identification of content items for the proposed instructional materials. Since teachers are experts regarding identification of their needs and problems, they were the right people to consult in this respect. Again, the guiding principle was the issue of relevance. For Jurgen Habermas, knowledge becomes more relevant with more practical application, relating theory to practice (Holub, 1991).

Findings in this chapter have clearly indicated the need to develop resource materials for professional teacher development. According to Powell and Anderson (2002), educational reform and the use of new materials usually go together. They maintain that discussing educational reform without referring to curriculum materials is pointless, since there is a significant role for materials as a vehicle for reform.

Dillon (2000) has highlighted the following issues appropriately in teacher education: initial disturbance or dissatisfaction; reflection on existing strategies; evidence base of successful teaching strategies based on models of learning; a source of new ideas; an opportunity to work with colleagues; coaching and mutual support; appraisal; encouragement from managers; feeling of personal growth; and a sense of ownership of innovation. Among all these factors, it is clear that there are several of

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these issues relating to this chapter. For example, when teachers in the study alleged that their initial teacher training was lacking in terms of preparation to teach certain subject areas, they were actually expressing disturbance and dissatisfaction with their training. In a way, this motivated them to seek ways of improving themselves professionally. This also meant that teachers reflected on their existing strategies. Teachers who participated in the proposed in-service programme appeared highly motivated by a feeling of personal growth and pride driven by a sense of ownership.

Where teaching and learning have occurred in collaborative environments, calls have been made to revisit the relationships between teachers and learners in view of their expectations of each other. For most traditional educators, it is very difficult to accept learners as partners in the business of teaching and learning. For example, during discussions with colleagues, where a draft of this chapter was brainstormed, there were those who struggled to appreciate the kind of student participation propounded in this chapter. Their argument was that if a learner participated in the development of a course or module that s/he would later register for, it might be difficult to assume the role of a learner. This shows how difficult it is for one to change from one school of thought to another. For the disciples of the 'banking concept of education', it appears difficult to respect or acknowledge the experiences learners bring to the classroom. According to this perspective, the learner is an empty vessel to be filled. This is why, instead of challenging students with problems in what Paulo Freire terms 'problem posing', they choose to provide solutions to given problems and then make sure students follow instructions as closely as possible (Ornstein and Hunkins, 1998).

The analogy of the physician and patient could perhaps help to explain the thesis of this chapter. When a patient comes to hospital, under normal circumstances, there is no way a doctor would simply rush in to treat the patient. Despite his/her qualifications, in most cases, the doctor consults the patient in order to establish the actual problem. And, no matter how well the patient explains the problem, there is no way s/he is declared a qualified physician. However, what cannot be disputed is the fact that the patient is the expert regarding the description of his/her suffering. S/he is the only one qualified to explain the intensity of his/her pain. So, in terms of pain, regarding the need for pedagogical knowledge, in this chapter the teacher, who happens to be the learner, is the expert. Paulo

Freire, in *Pedagogy of the Oppressed*, notes that the purpose of education is to enlighten the masses about their present state of being denied their rights, to design situations in which they recognise their state of being and feel dissatisfied with it, and, finally, to gain those skills and competencies required to correct identified inequalities for full emancipation (Ornstein and Hunkins, 1998).

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# *Theme: Relevance of Science and Mathematics education*

Research in Science and Mathematics Education has been (and is) dominated by research in cognitive dimensions. This focus has been exacerbated by the dissatisfaction of countries with the performance of their learners in international comparative tests such as Trends in International Mathematics and Science (TIMSS). There is a virtual silence on affective dimensions and the views of learners on what they would like to learn in school science and mathematics. The chapters in this section focus on the voices of the learners and what they would find relevant in their education.

Anderson *et al.* assess interest profiles in science and technology in Ghanaian secondary schools using the instruments developed by the large-scale international survey Relevance of Science Education (ROSE). The conclusions focus on a possible mismatch between the intended curriculum and learners' interests. In developing countries, such as Ghana, education is not very accessible due to, among other things, a lack of financial resources. Girls are most affected, despite the fact that their motivation to learn is high.

The chapter by Mavhunga *et al.* assesses the interests of Zimbabwean children in school science using the instruments developed by the ROSE survey. The overall finding is that schoolchildren have an intrinsic desire to learn about the issues around them. Another finding is that the children's interests are found to be far more diverse than the school science curriculum. The study reveals that girls tend to be more concerned about caring about other people, while boys are more interested in technical issues. It also highlights the need for Zimbabweans to produce curriculum materials that present scientific concepts and skills in contexts found in Zimbabwe, like information about bird flu, climate change and HIV/AIDS.

Julie and Holtman's chapter focuses on the viability of an instrument to assess the contexts learners would like to deal with in school mathematics. Using data obtained from six countries and subjecting it to Rasch analysis, they conclude that the instrument performs in accordance with Rasch modelling prescriptions. They continue

to compare the rankings of a selected number of items by the countries relative to the overall ranking positions of the items. The results throw up similarities and differences, especially when considering the developmental status of the participating countries.

# *16. What Kinds of Science and Technology Do Pupils in Ghanaian Junior Secondary Schools Want to Learn About?*

Ishmael K. Anderson, Sven Sjøberg and Øyvind Mikalsen

## **Abstract**

The topic treated in this chapter is based on a larger international study called Relevance of Science Education (ROSE). The chapter assesses the interest profiles of Ghanaian junior secondary pupils at the end of compulsory schooling in some 108 different topics in science and technology, which might be included in a science curriculum. The information obtained for this chapter is part of data collected from a sample of 1 027 pupils drawn from all the 12 districts in the Central Region of Ghana in the year 2003, using a standard ROSE survey questionnaire of 250 items that relate to some aspects of science and technology on a four-point Likert-type scale. In analysing the information through the use of SPSS and Excel, it becomes clear that the average level of interest in most topics is very high in Ghana. This high level of interest is common to all groups of pupils (male and female, urban and rural). When analysing details in the response pattern, one also notes that boys and girls, to a large extent, place the same items on top as well as at the bottom of their priorities. This is also seen among urban and rural pupils. The chapter also looks at areas where there is a mismatch between the interests of girls and boys, as well as between urban and rural pupils. Some of these differences are striking, and details on this are explored. We argue that data of the kind presented in this chapter could be taken into account in everyday teaching in classrooms as well as in the definition of curricula and the writing of textbooks.

## **Introduction**

In most developed countries, many young people appear to lose their interest in science and technology in school and further studies (Black and Atkin, 1996). It seems students have developed ambivalent attitudes to, and negative perceptions of, science and technology (Schreiner and Sjøberg, 2004). Whatever the reasons for this phenomenon, Ghana, as a developing country, cannot afford to follow the same trend. Ghana, like many African countries, is still faced with challenges of underdevelopment. Environmental preservation, combating and control of diseases, lack of a culture of self-employment after leaving school, population control, food production, health and sanitation are some of development-related challenges that confront most developing countries in Africa.

The Science and Scientist (SAS) study (Sjøberg, 2000, 2002), for example, reveals a considerable difference between students from different countries (including Ghana) in terms of what they are interested in learning about in science. Sjøberg found a low overall interest in science in Japan, confirming trends regarding science learning in developed countries. But students from developing countries, like Ghana, seem to be interested in learning about nearly everything. In general, students from developing countries are found to be far more interested than students from more economically developed countries. The pattern in gender differences in interests seems to be similar, but to varying degrees. The gender differences in developing countries are less pronounced, compared to industrial countries.

These are positive signs for Ghana that Ghanaian science educators could build on by introducing a sound science education programme that attracts the interest of all learners, regardless of their social or geographical background or gender. Hence, it is important to know the interests of students, and how this may vary according to their background. When such interests are considered in the process of designing science curricula, it is likely to make school science relevant to the needs of all learners and their communities. A science curriculum that takes cognisance of the needs and interests of students is likely to shift the traditional perspective of science education to providing students with meaningful and sound science learning opportunities. This is because the experience of the past two decades has brought about a strong awareness all over Africa that the present form of science taught in schools does not prepare pupils to function well in a society undergoing transition from a rural to a modern economy (Ogunniyi, 1986). In addition, school science, for some time now,

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has tended to act as preparation for those who will become professional scientists or for those attempting to pass standardised tests (Millar and Osborne, 1998).

School science should, however, function in a way that provides learners with a wider understanding of science, which will lead to more informed decision-making and social development of the community at large (Ware, 1992). In this context, science education should be relevant to those living in a particular society; acknowledge the political, social and cultural factors that affect the population; and be linked to local context and issues of sustainability (Kyle, 2001).

Despite the interest in science learning expressed in some studies, Ghanaian pupils' performance level at the Third [later: Trends in] International Mathematics and Science Study (TIMSS) was very low. It provides evidence of students' inability to recall science they have learned in school. A total of 5 114 Grade 8 students in 150 schools across the country were sampled in 2003. The eighth-grade (in Ghanaian it is the second year in junior secondary school – JSS2) pupils in the sample were made up of 45% girls and 55% boys. Ghana performed so poorly in the TIMSS 2003 that it ended up 44th out of the 45 countries participating in the test. The overall performance of Ghanaian students in mathematics and science was poor, placing them on average scores of 276 in mathematics and 255 in science (this is below international averages of 466 and 473, respectively). These two scores place the nation second from the bottom in the ranking for the two subjects. The performance in TIMSS 2003 indicates a better overall performance by boys than girls in all the content areas in science that were assessed (Anamuah-Mensah, Mereku and Ameyaw-Asabere, 2004). TIMSS 2003 results for Ghana were, however, not differentiated by urban/rural location.

There are many studies confirming that boys have a greater interest in many aspects of science than girls do (see Clarke, 1972; McGuffin, 1973; Gardner, 1985); with boys performing better than girls in most of the sciences (Avotri *et al.*, 2000). Available data in general science, taken at BECE<sup>1</sup> for the period 1995–1997, shows gender differences in performance in favour of boys. The performance in general science for boys and girls who obtained Grades 1 to 6 over the period areas follows: in 1995, 80.6% of boys as opposed to 73.7% of girls; in 1996, 76.3% boys and 69.2% girls. A similar pattern is seen in 1997, but girls showed some improvement in performance – 78.2% of boys as opposed to 75.3% girls (Avotri *et al.*, 2000).

The authors tend to believe that learners' lack of conceptual understanding in science might have accounted partly for the low performance levels among Ghanaian junior secondary school pupils in achievement tests and assessments. Ghanaians do, however, not seem to have a lack of interest in or poor attitudes towards science. This is because Ghanaian pupils have expressed overall interest in science learning, as indicated in the SAS study. In addition, reviews of literature on learners' conceptual understanding in science show that learners hold ideas about science that are contrary to those of accepted science, and hence in school science (Duit, 2004).

Studies have shown that a pupil's interest in the subject leads to deep learning (Hidi, 1990). We are therefore of the opinion that pupils' learning of scientific concepts can be improved when more attention is given to affective dimensions like attitudes, beliefs, values, appreciation or interest, when other factors such as school and home/community environments are controlled. Sjøberg (2002) and Fensham (2000) have also argued that a science curriculum whose content is determined by the needs of the child would produce a curriculum more relevant to the child of today. According to Sjøberg, children have different home backgrounds, life experiences, interests, attitudes, values and priorities; and these differences are important determinants in their learning (Sjøberg, 2002). It has, for instance, been observed that male and female pupils often have very different experiences of the same classroom (Jones *et al.*, 2000). It has also been suggested that humanistic perspectives in a science curriculum can improve the recruitment of students (Holton, 2003; Solomon, 1994).

Several contributing factors have been advanced for pupils' declining interest in science during their school careers in developed economies. One such factor is the apparent lack of relevance of the school curriculum to teenagers' curiosity and interest (Millar and Osborne, 1998). According to Jenkins (2000), the neglected issue of content examination may partly account for pupils' declining interest in science. Such a curriculum, as noted by Duschl (1990), can generate an ever-increasing gap between the scientific elite and the scientific illiterate. Debate in science education reform in this area has, however, shifted radically from how to prepare the next generation of scientists to how to prepare a scientifically literate society (Buxton, 2005). Ghana, as a developing society, cannot bear the consequences of alienation and the disengagement of the majority of its pupils with science that such a curriculum might generate. For this reason, the appraisal of science education curricula should be an ongoing process

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that provides input and feedback to guide, change and offer direction for the programme and its modification (Njoku and Anyakoha, 1992).

The arguments regarding science curriculum raised here seem to favour a localisation of the curriculum and the use of content that is related to familiar, interesting phenomena and pupils' experiences in the local environment (Nganunu, 1998). There is limited evidence to show that using relevant contexts leads to a better understanding of the concepts involved, compared to traditional teaching (Ramsden, 1997), but learning may take place more meaningfully and permanently if pupils are able to make connections between conceptual knowledge and familiar things around them. Furthermore, teaching *interesting* topics gives no guarantee that the teaching will be successful – although it is certainly better than choosing issues deemed by the students to be boring at the outset (Schreiner and Sjøberg, 2004).

Many studies address pupils' alternative conceptions in science. In these studies, as mentioned, researchers have found that school science learners hold ideas about science that are contrary to those of accepted science, and hence in school science. A survey of such studies is regularly compiled and updated by Duit (2004). This database now contains some 4 000 studies, which indicates the proliferation of such research. There are, however, considerably fewer studies that address the attitudinal aspects (i.e. attitudes, interests, motivation, etc.) of pupils' relationship to science and technology. Nevertheless, reviews have been published (e.g. Osborne, Simon and Collins, 2003), and there is increasing concern about such factors as important as conceptual understanding and achievement in tests and assessments.

The demands for conceptual understandings and achievements may, however, create a platform for some comparisons of the effectiveness of different teaching approaches at achieving stated learning goals. It is clear that instructional testing of this kind might not allow for judgements to be made about the interest or perceived relevance of school science to learners. Indeed, there are relatively few examples of research studies in science education that attempt to answer this question of learners' levels of interest in school science.

An important goal of this chapter, therefore, is to identify interesting science content knowledge for gender-inclusive, as well as urban/rural-inclusive, science education within the compulsory school level in Ghana. One way of doing this is to investigate what pupils are likely to have interest

in learning about; which might be considered in everyday teaching in classrooms, when science curricula are defined and when textbooks are written.

### **Ghana's educational reform in brief**

Ghana has seen various forms of educational reform since the attainment of independence in 1957. These include changes in the educational system, coupled with the development of new curricula at all levels of education. The fundamental nature of the education systems was considered pyramidal (with each level largely being a preparation for the next, narrower level); causing academic selection for universities to exert a controlling influence on what is taught in schools and how it is taught, rather than providing a broadly based, relevant or practical education which caters for all (Towse *et al.*, 2005). The range of science content is expected to extend beyond the traditional conceptual content of physics, chemistry and biology to include applications of science and technology. This is because Ghana, like most societies, is expected to undergo a significant change due to the influence of science and technology. Implicit in this is that the science, which is needed by present society, must be quite different from traditional science content. Despite this, one of the most significant aspects of the new science curriculum in Ghana is only a pragmatic reduction in the range of content in the 1980s and 1990s. This has resulted in the retention of much of the traditional content with little new material on technology and development. Hence, pupils continue to find the science they are learning at school isolated from their everyday experiences.

### **Science education and gender**

In most rural African societies women interact with the environment more than men do in the realm of agriculture and the tapping of other natural resources for domestic use; hence becoming the primary users of science in daily living (Avotri *et al.*, 2000). Therefore, science education for girls and women is a national asset for a developing nation in particular and any nation in general. Yet, Harding and Parker (1995) found in their research that everywhere women are poorly represented in areas of employment that require science-related qualification, other than in medicine and nursing. Ghana is experiencing a similar situation in that it has been observed that few girls take an interest in science and science-related subjects (Avotri *et al.*, 2000) and this has become an issue for concern within the Ghanaian

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educational system. The gender gap in the choice of science and science-related disciplines in Ghana is clearly seen after compulsory schooling; most notably in terms of physics being favoured by boys.

Numerous studies confirm that boys have a greater interest in many aspects of science than girls; with boys being more interested in physical science and girls being more interested in biological and social science topics (Jones *et al.*, 2000; Gardner, 1985; Mfuo *et al.*, 1997; Newman, 1997; Odaga and Heneveld, 1995). Apart from dropout rates and performance levels, which are worse for girls than for boys, the majority of girls who remain in the educational system tend to shy away from science, mathematics and technical subjects, opting instead for arts and social science subjects (Odaga and Heneveld, 1995). Investigating the factors that hinder girls' access to education in Ghana, Newman (1997) reported girls disliking mathematics and science. According to Mfuo *et al.* (1997), most girls regard science, mathematics and technical (SMT) subjects as masculine, and therefore difficult. One reason given for biology being preferred to physics by girls is that biology has been traditionally viewed by girls as a more caring branch of science that focuses on living organisms and human health; while girls view physics in the context of war and destruction (Jones *et al.*, 2000). In the same sample, Jones *et al.* showed that males reported significantly more interest in learning about the listed science topics from a variety of sources. In addition, there were 20 different topics in which more males than females reported being interested, and there were only six topics where more females than males indicated interest.

In a study conducted by Avotri *et al.* where a sample of 1 132 Ghanaian pupils was asked to rate the subjects in the school curriculum on a three-point scale. They were to indicate whether they found each subject easy, average or difficult. The findings indicated that most pupils found all the subjects easy, with music and mathematics being the easiest and most difficult subjects, respectively. Boys found mathematics and integrated science easier than the girls did, but the differences between their average responses were small (Avotri *et al.*, 2000). Studies elsewhere have indicated similar findings.

### **The ROSE project in Ghana**

ROSE, an international project with about 40 participating countries, is coordinated by Sjøberg and Schreiner at The University of Oslo and supported by the Research Council of Norway. Reports and details of

the ROSE questionnaire and information about countries involved are available at the project website.<sup>2</sup>

The ROSE project aims at exploring some affective qualities of science teaching and learning in order to provoke some thoughts and stimulate informed discussion about science curricula in various cultural and societal contexts. The ROSE questionnaire items, developed by the authors (a team of science education researchers from all continents) over 18 months, have been trialled in different countries, including some European and African countries. The questionnaire focuses on a variety of items that are familiar in different cultures, thus befitting large-scale international collaborative study. Details are given by Schreiner and Sjøberg (2004).

## **Methodology**

For the data collection the standard survey methodology is employed. A standard ROSE questionnaire, which has been pre-tested in many countries on all continents (including Ghana), was used to obtain information from Ghanaian junior secondary school pupils. The first author collected the data.

The responses from the ROSE questionnaire were analysed using computer programs (SPSS and Excel). An independent sample two-tailed t-test was used to explore the statistical significance of the differences in the items' means. The conventional  $p \leq 0.05$  level of probability was used as the basis for reporting the differences in means between boys and girls' scores and between urban and rural pupils' scores as being statistically significant.

## **Population**

The target population consisted of all the pupils in the last year of compulsory schooling in Ghana in the year 2003 – the third year in junior secondary school (JSS3, or Grade 9). The pupils' normal ages range between 14 and 16 years, with a modal age of 15 years. Most of these schools are co-educational (male and female pupils). Although this work is geared towards all junior secondary school pupils in Ghana, it was not possible to cover the entire country due to constraints such as logistics, time, accessibility and human resources.

Ghana is divided into ten regions, with about 70% of the population living in rural areas. At the time of data collection (2003), Ghana had 110 districts from the ten regions; the number of districts was, however, later increased to 138. Owing to some constraints, as mentioned above, we

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had to balance 'ideal' requirements against practical constraints in order to confine the study to the Central Region of Ghana. The choice of this region is based on the following assumptions:

- The researcher is very familiar with this region.
- The ROSE instrument was previously tried with Ghanaian junior secondary school pupils in this region.
- The junior secondary school science curriculum – including syllabi, schedules, exams, marking systems and textbooks – is determined by the Ministry of Education and is identical in all Ghanaian junior secondary schools. All pupils, therefore, potentially have the same opportunity to learn the same science concepts.
- Furthermore, the country as a whole is following one type of educational system, and all pupils take one national examination conducted by the West African Examinations Council.

Compulsory schooling in Ghana comprises nine years – six years of basic schooling (ages 6–12; BS1–BS6) and three years of junior secondary education (ages 12–15; JSS1–JSS3). However, the national average school age of the participants is 15 years. Junior secondary school pupils sit for Basic Education Certificate Examination (BECE) at the end of the third year (JSS3). This is a common national examination conducted by the West African Examinations Council.

### **Sample, sampling techniques and participation**

In selecting the pupils that participated in this study, all 12 districts in the Central Region of Ghana were clustered into urban and rural schools. All the schools in the district capitals were operationally defined and regarded as urban schools. Localities of 5 000 persons and above have been classified as urban since 1960 (GIR, 1994). Urban areas in Ghana have more amenities than rural locations and district capitals are therefore characteristic of urban settlements.

A total of 1 027 JSS3 pupils from 24 schools were used. The 24 schools were randomly selected from the 12 districts in the Central Region of Ghana. The schools are representative of urban and rural settlements. Two schools, one urban and one rural, were randomly selected from each district. A stratified random sampling technique was used to choose the schools. A table of random numbers was used to guarantee that every school

in each stratum (urban/rural) had an equal chance of being selected. The numbers of male and female pupils that took part in this study are 551 and 476, respectively. The numbers of urban and rural pupils are 613 and 414, respectively.

For practical and financial purposes, as already mentioned, the authors conducted this study in Central Region (one of ten regions). Although the sampled area was quite homogeneous in terms of school type, survey samples are very small and by no means representative of the larger Ghanaian communities in which respondents reside. Respondents' answers may, however, prove very useful in canvassing the range of views that exists in the sampled area.

It is envisaged that through the data analysis the study will provide interesting insights and that the findings could arguably be generalised for the entire country. The findings may also serve as a basis for further studies.

### **The ROSE instrument**

The ROSE questionnaire has a large number of items (250, under eight sections) on a four-point Likert-type scale. Although the ROSE questionnaire has a large number of items, only 108 items (considered relevant to this chapter) were used. These items are on topics or themes the pupils have an interest in learning about. The items, which are of a four-point Likert-type scale rating, range from 'Not interested' to 'Very interested'. A 'Do not know' category is omitted. The rationale behind this is that the respondents are in a way 'forced' to take a stance. This is arguably done in such a way that 'too many' scores on the neutral boxes category may be avoided in order to bring diversity in the responses.

'What I want to learn about' is the theme for sections A, C and E in the instrument. These three sections invite pupils to give answers to a series of questions about what they would like to learn. The central idea is to get empirical evidence on what issues pupils are interested in learning about, and to explore how these vary between groups and search for patterns in the answers. This may provide insight into whether or not different topics appeal to different groups of learners. The information can give one an insight into how science curricula may be constructed to meet the perceived needs or interests of different groups of pupils.

## **Results and discussion**

### **Boys and girls**

The ROSE questionnaire included a series of topics relating to science and technology and the students indicated their levels of interest on a four-point Likert-type scale. The set of topics was chosen to reflect different aspects of science: the more 'mechanical' aspects (like how car engines work), the more social or health aspects (like nutrition and exercise) and topics that relate to natural phenomena (earthquakes, rainbows, etc.).

Mean scores for each variable are calculated for boys and girls separately, as well as for urban and rural students. The most popular and the least popular topics for each of these groups are compared in Table 1 and Table 2. The topics appearing on both lists are listed in bold.

It is very noticeable that boys and girls selected similar interesting or unappealing topics. An overall high level of interest in almost all the science topics is found for all groups of pupils, with mean values ranging from 3.48 to 2.12 for girls, and 3.47 to 2.18 for boys. The neutral response value is 2.5. These values are considerably higher than the corresponding numbers for industrialised countries, but are similar to results from many developing countries.

A likely explanation for these observations may be that in developing countries like Ghana education is not very accessible due to some cultural practices and lack of logistical and financial resources. Girls are affected most, because for them education and learning appear to be luxury. Hence, they may show their curiosity about almost all the topics on the list. There is therefore a high motivation for both sexes to learn and study. They tend to indicate an eagerness to learn about almost every topic. As can be seen from Table 1, the 'top ten' topics are not very different for boys and girls. The list reflects strong interests in topics related to the self, especially to health and well-being. It seems that girls and boys agree on the importance of learning about diseases (such as HIV/AIDS), adequate nutrition, food security, good sources of drinking water and good health. These topics are of personal and societal relevance, and are also some of the biggest challenges facing most African countries (including Ghana). This is reflected in the responses of the learners.

**Table 1: The ten most popular topics for girls and boys in Ghana  
(items appearing on both lists are in bold)**

Girls' topics	Mean
How computers work	3.48
What can be done to ensure clean air and safe drinking water	3.48
How my body grows and matures	3.47
What to eat to keep healthy and fit	3.47
How to exercise to keep the body fit and strong	3.44
How mobile phones can send and receive messages	3.40
How the eye can see light and colours	3.37
<b>Electricity, how it is produced and used in the home</b>	3.36
<b>What we know about HIV/AIDS and how to control it</b>	3.33
How plants grow and reproduce	3.26
<b>Boys' topics</b>	
How computers work	3.47
How my body grows and matures	3.46
What to eat to keep healthy and fit	3.45
What can be done to ensure clean air and safe drinking water	3.45
How to exercise to keep the body fit and strong	3.44
How mobile phones can send and receive messages	3.44
How things like radios and televisions work	3.41
<b>Electricity, how it is produced and used in the home</b>	3.41
<b>What we know about HIV/AIDS and how to control it</b>	3.37
Sexually transmitted diseases and how to be protected against them	3.35

These results suggest that Ghanaian pupils see these topics as important with regards to school science, and show little variation in interests towards these areas for boys and girls. We may therefore deduce that a strong interest in a given topic may be the same for both sexes. Pupils of both

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sexes are also strongly attracted by topics that can be described as modern technology; for example: ‘How computers work’ and ‘How mobile phones can send and receive messages’. The majority of pupils who responded to the questionnaire do not have access to these types of technology (neither at school nor at home), a factor which might explain why they exhibited such strong interest in these topics. It is also noteworthy that both sexes show high levels of interest in learning about HIV/AIDS and how to control it as well as ‘What to eat to keep healthy and fit’. It appears that these topics have high relevance to the students’ lifestyles and are therefore attractive to both boys and girls.

A similar pattern is found when we turn to Table 2, which lists the ten least popular topics with pupils responding to the questionnaire.

**Table 2: The least popular topics for girls and boys in Ghana (items appearing on both lists are in bold)**

Girls’ topics	Mean
<b>Alternative therapies (acupuncture, homeopathy, yoga, healing, etc.) and how effective they are</b>	2.35
<b>Unsolved mysteries in outer space</b>	2.34
<b>Dinosaurs, how they lived and why they died out</b>	2.34
<b>Eating disorders like anorexia or bulimia</b>	2.31
Brutal, dangerous and threatening animals	2.30
<b>Tornadoes, hurricanes and cyclones</b>	2.28
<b>Black holes, supernovas and other spectacular objects in outer space</b>	2.24
<b>Cloning of animals</b>	2.19
<b>Ghosts and witches, and whether they may exist</b>	2.12
<b>Boys’ topics</b>	
<b>Plastic surgery and cosmetic surgery</b>	2.42
<b>Unsolved mysteries in outer space</b>	2.32
<b>Cloning of animals</b>	2.30
<b>The ability of lotions and creams to keep the skin young</b>	2.26

Alternative therapies (acupuncture, homeopathy, yoga, healing, etc.) and how effective they are	2.24
Dinosaurs, how they lived and why they died out	2.20
Eating disorders like anorexia or bulimia	2.18
Black holes, supernovas and other spectacular objects in outer space	2.18
Ghosts and witches, and whether they may exist	2.17
Tornados, hurricanes and cyclones	2.15

The overall picture is that the same topics are unappealing to both boys and girls. The mean scores here are less than 2.5 on the four-point scale. 'Black holes, supernovas, and other spectacular objects in outer space', 'Ghosts and witches, and whether they may exist' are at the bottom of the list in terms of popularity. Apart from the topic on ghosts and witches, almost all the ten least appealing topics for both girls and boys are either phenomena or processes in science, which are perceived to be unfamiliar in Ghanaian context. They therefore appear to have low levels of interest in learning those topics, probably because of perceived lack of personal relevance. Myths about ghosts and witches are, however, very common in Ghana. It is interesting to note that the pupils do not consider this to be a topic they would like to learn more about at school.

Table 3 focuses on gender differences. We want to focus on differences between boys' and girls' responses. With large samples, like we have with ROSE, even very small differences between means of groups can become statistically significant. This does not mean that the difference has any practical, theoretical or educational significance (Pallant, 2001). However, it is worth commenting on the differences in order to characterise different interest profiles. There are few examples of large gender differences in interests for girls and boys, but there are some, and we will briefly comment on these based on the information in Table 3. In the table, the list is sorted in ascending order for the difference, where the boys' mean is subtracted from the girls' mean. The p-value in the last column is a measure of the statistical significance of the difference. Only items with statistically significant ( $p < 0.05$ ) gender differences are given in the table.

On the list in Table 3, the 'male' items appear on the top, the 'female' at the bottom. We note that applications of physics have different appeal

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for boys and girls. Boys tend to be more attracted to the topics that are perceived to have mechanical or practical relevance, while girls tend to be drawn to topics related to health, beauty and social relevance. For example, boys show significantly higher enthusiasm for learning about ‘How things like radios and television work’, ‘Optical instruments and how they work’, ‘The use of satellite for communication and other purposes’, ‘How to use and repair everyday electrical and mechanical equipment’, ‘How petrol and diesel engines work’, and ‘Rockets, satellites and space travel’.

**Table 3: Statistically significant gender differences in science topics. Mean values are given for girls and boys, with standard deviation (SD) and p-value**

Topics	Girl mean (SD)	Boy mean (SD)	Mean Difference (girls-boys)	p-value
Rockets, satellites and space travel	2.78 (1.08)	3.01 (1.08)	-0.23	0.001
Sex and reproduction	2.71 (1.18)	2.92 (1.12)	-0.21	0.003
The use of satellites for communication and other purposes	3.05 (1.00)	3.25 (0.93)	-0.20	0.001
How petrol and diesel engines work	2.84 (1.03)	3.03 (0.98)	-0.19	0.003
Optical instruments and how they work (telescope, camera, microscope, etc.)	3.14 (0.95)	3.32 (0.89)	-0.18	0.002
How things like radios and televisions work	3.25 (0.92)	3.41 (0.81)	-0.16	0.005
Inventions and discoveries that have changed the world	2.78 (1.01)	2.93 (1.02)	-0.15	0.029
Stars, planets and the universe	3.10 (1.01)	3.24 (0.96)	-0.14	0.028
The ozone layer and how it may be affected by humans	2.70 (1.09)	2.84 (1.09)	-0.14	0.047
How to use and repair everyday electrical and mechanical equipment	3.05 (0.91)	3.19(0.96)	-0.14	0.022
How the human body is built and functions	3.17 (1.01)	3.29 (0.93)	-0.12	0.048

Phenomena that scientists still cannot explain	2.76 (1.13)	2.68 (1.15)	0.08	0.028
Risks and benefits of food additives	2.80 (1.05)	2.67 (1.05)	0.13	0.045
Symmetries and patterns in leaves and flowers	2.74 (1.11)	2.59 (1.08)	0.15	0.031
How radioactivity affects the human body	2.64 (1.07)	2.47 (1.15)	0.17	0.027
Properties of gems and crystals and how these are used for beauty	2.76 (1.05)	2.53(1.05)	0.23	0.001
The ability of lotions and creams to keep the skin young	2.52 (1.14)	2.26 (1.12)	0.26	0.000

In contrast, Table 3 tells us that girls are significantly more interested in learning more about 'Properties of gems and crystals and how these are used for beauty', 'Symmetries and pattern in leaves and flowers', 'How radioactivity affects the human body', 'The ability of lotions and creams to keep the skin young', and 'Phenomena that scientists still cannot explain'. We note that these topics are geared towards beauty, aesthetics, self and wonder. Some of them are related to biology.

Our findings above are in line with findings from earlier studies in many cultures (i.e. Clarke, 1972; Gardner, 1985; Mc Guffin, 1973). Our evidence also gives further credence to results from the SAS study (Sjøberg, 2002). However, an interesting aspect is that most of the topics are rather gender neutral. Only 17 out of the 108 topics had statistically different means for boys and girls, and all of these are presented in Table 3 above.

### Urban and rural school pupils

The data have also been analysed in the same way from an urban/rural perspective, which is an important indicator in many countries (developing countries in particular). Full results are given in the thesis.

We note that pupils from urban and rural schools have very similar preferences for the science topics. They have similar popular and unpopular interests. It is interesting to note that while urban pupils express the highest level of interest in wanting to learn about 'how computers work', rural pupils were most interested in 'how mobile phones can send and receive messages'. Availability of extensive educational resources in the home may have a great influence on motivation to learn or learning. A

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greater percentage of pupils lack access to resources like computers, both at home and at school. Pupils from the rural areas are most affected. Almost all the rural areas in Ghana where this study was conducted are not connected to the national electricity network and therefore lack electric power, on which electronic devices like televisions and computers rely for their operation.

The choice of topic on computers as one of their preferences suggests that most rural students might have been informed about something called a 'computer', but have neither seen nor had access to one. Pupils in urban areas might have access to computers through Internet cafés, and a privileged few may have access to computers at home. This might have influenced their expression of eagerness to learn about computers. The mobile phone has now become a commonplace object in Ghana. It has become fashionable both in urban and rural areas. This therefore leaves room for enjoyment and curiosity for pupils, especially those from rural areas, to know more about 'how mobile phones can send and receive messages'. It is also not surprising to note that the topic 'How plants grow and reproduce' is on the list of most preferred topics by the rural school pupils. This is because farming is the mainstay occupation in the rural areas, and all students are heavily involved. It is therefore expected that they will have high levels of interest to learn about such a topic.

Pupils from both urban and rural schools selected similar least appealing topics. Pupils seem to perceive these science topics as lacking relevance in their everyday life. Apart from 'Ghosts and witches, and whether they may exist', all the least appealing topics or phenomena appear contextually unfamiliar to them. Interesting television programmes about science, the environment and technology, which might bring students closer to some of these topics, are lacking in Ghana. Even if these programmes do exist, pupils from rural schools will be at a disadvantage in terms of accessing this material, compared to their counterparts in the urban settings. There are statistically significant differences between urban and rural school pupils' mean responses on some of the selected science topics, but there is no clear pattern emerging from these differences.

### **Implications for reviewing the junior secondary science curriculum in Ghana**

It is argued that if children are not comfortable or happy they will not learn, irrespective of how well pedagogical practices are designed. Despite

the critics of affective domain and the claim that pupils will feel good at the expense of becoming educated, the choice to study science, when students are asked, may be motivated by various reasons, such as being both interesting and useful for finding employment. Hence, a science curriculum whose content is determined, or at least influenced by, the expressed needs and interests of children, may produce a curriculum more relevant to the youth of today. It has been shown by many studies that rewriting the science curriculum based on what we know about student's interests may dramatically change their attitudes to and learning of the subject. Traditionally, science has been taught on the premise that all students could and should become practising scientists. While the reality is that very few students in science classes will become scientists, all students have a right to a good science education. Students who choose science or professional science appear to represent less than the percentage envisaged by Ghana, as mentioned in the Ghanaian National Science Policy document. What the country needs now is a working definition of science that promotes teaching and a curriculum that is geared towards producing scientifically literate citizens.

Although the number of topics or themes to 'learn about' in the ROSE project questionnaire is extensive (there are 108), there may well be topics not included that students would have shown an interest in learning about. In spite of the large sample size, this study's results are confined to the region where data were collected. The respondents' answers may, however, prove very useful in canvassing the range of views that exist in this region. These may further inform the decisions to improve the quality of science education in Ghana. There is therefore a clear message to curriculum designers in this regard. If all the pupils are making what might be called a right decision in expressing their (respondents') levels of interests, then we cannot exclude the voice of the students themselves in promoting quality science education in Ghana. The data has also made it clear that pupils' interests in science depend both upon the science content and its context, and, as we have shown, also upon gender and geographical context. A look at some of the gender as well as urban and rural pupils' preference topics and themes shows that it is vitally important to balance a science syllabus so that topics that have a natural appeal for girls and boys, as well as those preferred by urban and rural students, are included.

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### **Conclusion**

In the intended science curriculum, emphasis is placed on learners knowing basic science facts, understanding science concepts, learning about the nature of science and enquiry, and writing explanations about what is observed and why what is observed happens. However, less emphasis is put on the science topics which interest students, especially with regards to learning about modern technology – as was reported by the students who took part in this study. The national curriculum contains policy statements about the use of computers in teaching, but computers are not available to most students (Anamuah-Mensah, Mereku, and Ameyaw-Asabere, 2004). These are some of the contextual factors that impact on effective learning. Although we do believe it is desirable to consider views of students on science content in designing curriculum, we do not argue that science curriculum should be determined solely from the perspective of what students find interesting. A balance between their views and the specifics expected by subject-matter specialists would, however, be a good compromise. Teaching interesting content topics does not necessarily mean that good learning will be fulfilled; but it makes sense that students will be more motivated to learn about what interests them than what they perceive to be boring.

If science for all is an issue of concern, then, within the structure of Ghana educational system, proper attention should be paid to the structure and nature of the science course in junior secondary school. The voice of the students should be heard when curricula are revised and when teachers implement the curriculum in their classrooms.

### **Endnotes**

- <sup>1</sup> In Ghana, junior secondary school students sit for Basic Education Certificate Examination (BECE) at the end of the third year (JSS3). This is a common national examination conducted by the West African Examinations Council. Among other subjects, they are expected to pass general science at the BECE to gain admission to the middle-level education.
- <sup>2</sup> <http://www.ils.uio.no/forskning/rose>

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# *17. What Are the Interests of Zimbabwean Secondary School Children in School Science?*

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## **Abstract**

This chapter reports on the interests of Zimbabwean children in school science. Children's interests and perceptions about science and their future were examined by the Relevance of Science Education (ROSE) questionnaire. Twenty-one schools representing the spectrum of schools in Zimbabwe were sampled in 2003. A descriptive analysis of learners' interests and expectations of science education showed them to have a high level of interest in science. Girls tended to have interests that were more inclined to caring about other people, the environment and their personal welfare. Boys' interests were more focused on technical issues. Overall children's interests are found to be far more diverse than the school science curriculum.

## **Introduction**

School science is the foundation for human-resource and technological development and school science education aims to enable all citizens to command an understanding of issues in a world that is increasingly dependent on scientific solutions. Future scientists and technologists also emerge from the science education process that starts in the school system. In spite of all the positive outcomes of science education, several social challenges compete for the attention of secondary school children. The literature is replete with studies that indicate low interest in science among schoolchildren.

The tradition in science education is that schoolchildren generally encounter a pre-formulated curriculum in the school system. While social constructivism centres on the child, effort is rarely made to include the voice of the learner in science education. In this chapter, we report some interests expressed by Zimbabwean secondary schoolchildren in science. It is important to acknowledge that children are confronted with a wide range of fundamental issues that contribute to their interest in science. Socio-cultural, economic and personal values are all possible influences on children's interest in science. The authors' aim is to explore these interests. An analysis of the contexts within which Zimbabwean children live will be made. It is the authors' view that debate about science education in Zimbabwe must be informed, among other things, by the kind of interests shown by children. The authors believe that while an expression of interest in an aspect of science is not necessarily writing the curriculum, it is a means of understanding where learners' motivation lies and, hence, providing insight into their expectations of a science education.

### **The need to focus on children's affective interests**

For many years education in southern African Anglophone countries was linked to British examination systems. In Zimbabwe, independence brought a realisation that the education system needed to promote national values and aspirations. Localisation of curriculum design and examinations became an urgent necessity. Localisation, also referred to as contextualisation, aimed to make the process and products of education more relevant and more compatible with the needs of Zimbabwe and to instil a sense of national ownership of the education system (Chung and Ngara, 1985; Kanyongo, 2005; Nherera, 2000;). The Zimbabwe School Examinations Council website<sup>1</sup> explains the reasons for localisation as follows:

To effectively cater for the local content aspect of the curriculum in examinations, to save foreign currency thus making examinations affordable, for flexibility in curriculum development, in the interest of relevance to our environmental context.

The process of localisation needs to incorporate the interests of all stakeholders. Learners are significant stakeholders in an education system, yet they rarely make any input into the curriculum. The authors

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acknowledge that a great deal of good research has been done on the process of localisation and aim to add the dimension of secondary schoolchildren's interests to that body of research.

### **What are interests?**

There are many stimuli in a child's environment that are used to compose concepts and attitudes about science, and children are routinely exposed to a proliferation of global and local issues rooted in scientific debate via the media and everyday experience. Issues such as HIV/AIDS, for instance, affect every child in Zimbabwe in one way or another. Priority issues are therefore of concern to them and they display a keenness towards them in order to better understand, be able to react to these issues and possibly have an impact on them. Interest is an expression of the importance attached to an issue.

The extent to which one is interested in an issue varies from outright distaste to very positive commitment. The nature of interests also varies quite widely, depending on the significant influences that exist in the life of an individual. For instance, a labourer's child growing up on a Zimbabwean farm is likely to be more interested in animals and growing plants than in lotions for keeping the skin looking young. It can in fact be assumed that the interests of children are the result of the sum total of his/her experiences. Life experiences consist in the economic, social, biophysical, cultural and political environments of the child.

### **The Relevance of Science Education study (ROSE)**

The ROSE study is a unique cross-national comparison of the interests and views of secondary schoolchildren in science and technology issues. It is unique in that it is a relatively low-cost international comparative study focusing on children's attitudinal dimensions. While it has uniformity in that it uses the same questionnaire, it is also easily adaptable to local purposes in any country. Other attitudinal surveys have been largely limited to localised samples, or have been designed to inform pedagogical debate at national levels. Comparable international surveys such as the Organisation of Economic Cooperation and Development (OECD)-based Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) tend to be more diagnostic with regards to cognitive achievement and are not especially concerned with affective issues (Schreiner and Sjøberg, 2004).

The ROSE study is based on the realisation that every aspect of life is influenced by science and technology (Schreiner and Sjøberg, 2004), irrespective of whether the science and technology is simple or sophisticated. Life in the Kalahari is therefore influenced by the locally existing level of appropriate science and technology as much as life in Japan. The ROSE study makes cross-national comparisons of secondary schoolchildren's views about science and technology, the importance they attach to science, their interest in it and their perception of the relevance of science for their future. The study was conducted in Zimbabwe and 32 other countries and provides a unique opportunity for cross-national comparison of children's perceptions about science and science education. The Rose study's sensitivity to cultural diversity and personal motivation of the learner is critical for informing processes of policy development and debate on science and technology issues in different nations.

### **The ROSE instrument**

The ROSE project gathers indications of the attitudes of children near the end of compulsory secondary education – usually around 15 years of age. The purpose of the ROSE study is to analyse and deduce trends in children's views across countries of widely different economic, political and cultural backgrounds. Towards this end, a questionnaire was developed in Norway by Sjøberg (2002) in consultation with a wide range of experts and participants. The same questionnaire was used in all participating countries. This approach made it possible to make international comparisons in the interests and views of children regarding science and their lives. The interpretation, implications and use of responses varies from one country to another. Common trends do, however, emerge between different countries, and these can inform theory and practice of science education.

The ROSE questionnaire consists of attitudinal questions about various aspects of science and technology and science education in human life. All questions are answered on Likert-type scales ranging from one to four. The questions do not seek right or wrong answers, but require the children to express their feelings on the Likert scale. For statements of what they would like to learn about, respondents indicate their own level of interest as: (1) not interested, (2) low not interested, (3) low interested and (4) very interested. In the core questionnaire, each section maintains the same pattern of responses with other appropriate words to describe children's views. It is significant to note that the questionnaire does not have the

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option of 'not sure' or 'not decided'. It makes a subtle requirement that the respondents make a decision about what they really think and not 'hide' under the option of 'not decided'. The questionnaire was originated in English and no translation was required in Zimbabwe. However, respondents were free to ask whoever was administering the questionnaire about anything they did not understand.

For the purpose of using the same questionnaire across different cultures, items had to reflect a high degree of face and cultural validity (Schreiner and Sjøberg, 2004). The 246 ROSE questionnaire items were grouped according to seven underlying constructs: What I want to learn about, My future job, Me and the environment, My science classes, My opinions about science and technology, My out-of school experiences, and Myself as a scientist. In this chapter we report on 108 questionnaire items from the sections entitled 'What I want to learn about'.

### **The Zimbabwe ROSE study**

The ROSE questionnaire was administered in Zimbabwe from March to June 2003. Twenty schools participated in the survey. The schools were selected from Mashonaland Central, Harare and Bulawayo provinces. The selected schools are categorised as follows:

- Urban low fee-paying, government-assisted schools.
- Urban high fee-paying, government-assisted schools.
- Private high fee-paying schools.
- Rural day secondary schools.
- Rural boarding and mission schools.

This selection of schools represents the spectrum of schools that are found in Zimbabwe. The rural schools sampled children living in the rural and farming communities. These children are normally from families earning far below US\$ 400 per year (2005 exchange rates). They also have little or no access to modern science and technology.

Rural boarding and mission schools mainly enrol children from middle- and high-income families. Such schools are expensive and unaffordable for the rural communities in which they are located. Some of the highest achieving schools in the country are in this category. These schools were built by religious missions or government and are historically well endowed. Children here come from families that can afford to pay school fees of at least Z\$20million per term (US\$ 100) (2005 averages).

Urban high fee-paying, government-assisted schools pay a fee that is stipulated for urban schools by the Ministry of Education, but parents agree to pay substantially higher levies in order for the schools to operate in the desired fashion. Fees in excess of Z\$2 million are paid every term. Children commute to and from school, so the total expense for sending children to such schools is quite high for the average Zimbabwean.

Private high fee-paying schools levy fees in excess of Z\$24million (2003 statistics). These are children from obviously wealthy families. Some parents here are executives of large multinational companies, diplomats or wealthy businesspeople. The lifestyles of such children compare favourably with those in middle- or higher-income countries. Private schools are well endowed and afford a wide curriculum, usually including fairly exclusive sports, computer studies, music and other activities that are a pipe dream for the rural day schools.

A total of 735 children in Form 3 responded to the questionnaire. The ROSE questionnaire targeted children in their penultimate year of compulsory secondary education. The mean age from the Zimbabwe sample was found to be approximately 16 years.

## **Analysis of Zimbabwean ROSE data**

### **Grouping of respondents according to school type**

Respondents were grouped according to their type of schools. It is important to note that different schools enrol children from different economic levels of society. While the boundaries are not clear cut, the majority of students in a high fee-paying schools live above the economic levels of children enrolled in farm and rural secondary schools. The influences in their lives are definitely different and such differences are not insignificant.

### **Gender grouping of responses**

Similarities and differences in social experiences of boys and girls have been the subject of many gender relational studies. We consider that gender-based experiences are one of the many influences on the attitudes of children towards science and technology issues. The analysis of our survey of responses from Zimbabwean children endeavours to explore and describe any patterns and trends that exist.

The items for the construct of interest in science asked what the children would like to learn about in and out of school. From the total sample, mean

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values (range 1–4) on interest items were arranged in order of popularity for both sexes. Table 1 summarises the top ten interests for both sexes.

From a descriptive point of view, gender biases in the interests of Zimbabwean secondary school children are evident. Five of the most popular items for boys are related to desire for technical matters (bold in Table 1). These technical items have a common underlying feature of constituting relatively new information technologies for the general public in Zimbabwe. However, boys also show that they have an interest in health-related issues in five of the top ten items. Girls and boys show common interests in issues of sex and HIV. Given that Zimbabwe has the fourth highest percentage HIV infection rate in the world, it is encouraging to note that there is a common desire by all the sampled youths to learn about HIV/AIDS. For girls, interests tend to be mainly in biological issues and their interests can be regarded as more inclined towards caring for humankind. Girls' choices are likely to confirm the way gender differences exist in the affective make-up of children. This can also be regarded as evidence of traditional role stereotypes in the Zimbabwean gender equity perspective (Institute of Development Studies, 2003). Concerning the least popular interest items, lack of familiarity with some of the items is a possible reason why these were least popular. Dinosaurs, outer space and other spectacular phenomena are likely not to be in the daily experiences of the children. In several schools, children enquired about the meanings of terms such as acupuncture, yoga, black holes, cloning and many others. The major source of information about scientific issues is the media, schoolbooks and libraries. While the country has a 90% literacy rate, the culture of reading is limited by the lack of reading material (UNDP, 2005). Reading for the sake of passing examinations usually takes precedence over reading for general knowledge and leisure. Books are also shared in most of the schools.

### **Interests according to nature of questionnaire item**

Questionnaire items that sought children's interests can be classified into two broad types. There are items that specify interest in seeking knowledge for its own sake. Such interest is perhaps found in all children by virtue of their natural curiosity. Life experiences both in and out of school tend to influence children's interests.

**Table 1: Ten items with highest averages for boys and girls**

Questionnaire item	Average for girls	Questionnaire item	Average for boys
E9. Sexually transmitted diseases and how to be protected against them	3.73	<b>C7. How computers work</b>	3.65
E11. What we know about HIV/AIDS and how to control it	3.63	E9. Sexually transmitted diseases and how to be protected against them	3.59
E23. How my body grows and matures	3.62	E11. What we know about HIV/AIDS and how to control it	3.55
C7. How computers work	3.61	<b>C6. How mobile phones can send and receive messages</b>	3.53
A37. What to eat to keep healthy and fit	3.60	E5. What can be done to ensure clean air and safe drinking water	3.53
E8. Cancer, what we know and how we can treat it	3.57	<b>C5. How things like radios and televisions work</b>	3.51
E5. What can be done to ensure clean air and safe drinking water	3.56	A9. Sex and reproduction	3.50
E10. How to perform first-aid and use basic medical equipment	3.55	C4. How cassette tapes, CDs and DVDs store and play sound and music	3.50
A40. How to exercise to keep the body fit and strong	3.54	E23. How my body grows and matures	3.50
E7. How to control epidemics and diseases	3.53	<b>C3. The use of lasers for technical purpose (CD-players, bar-code readers, etc.)</b>	3.47

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**Table 2: Ten items with the lowest averages for boys and girls**

Questionnaire item	Average for girls	Questionnaire item	Average for boys
C12. Alternative therapies (acupuncture, homeopathy, yoga, healing, etc.) and how effective they are	2.58	A35. How to find my way and navigate by the stars	2.69
A14. Dinosaurs, how they lived and why they died out	2.56	A41. Plastic surgery and cosmetic surgery	2.63
A44. Rockets, satellites and space travel	2.50	C9. Astrology and horoscopes, and whether the planets can influence human beings	2.62
E37. Famous scientists and their lives	2.48	A12. Cloning of animals	2.60
C10. Unsolved mysteries in outer space	2.38	C12. Alternative therapies (acupuncture, homeopathy, yoga, healing, etc.) and how effective they are	2.60
C1. How crude oil is converted to other materials, like plastics and textiles	2.36	C10. Unsolved mysteries in outer space	2.56
E24. Animals in my area	2.33	C14. Ghosts and witches, and whether they may exist	2.53
A12. Cloning of animals	2.30	A22. Black holes, supernovas and other spectacular objects in outer space	2.52
A22. Black holes, supernovas and other spectacular objects in outer space	2.17	A38. Eating disorders like anorexia or bulimia	2.45
E1. Symmetries and patterns in leaves and flowers	2.09	E1. Symmetries and patterns in leaves and flowers	2.15

### **Factor analysis of questionnaire items**

Several items in different sections of the questionnaire were made similar in order to reliably measure underlying traits. For reliable interpretations and conclusions to be made about the various constructs, multiple item groups or composite variables were factored out (Gliem and Gliem, 2003). For emphasising arguments, graphs for single items may be given, but this does not mean that conclusions are drawn from single items. The weakness of single items in measuring underlying constructs is well researched (Gliem and Gliem, 2003).

Cronbach alpha values measured the internal consistency of composite variables. Clearly, some items may statistically factor out together, but do not make logical sense; while others would make very logical sense without necessarily factoring out together or may have rather low Cronbach alpha. As a further test, if the grouped items measured the same construct their inter-item correlation was also considered.

### **Factor 1: Human reproduction**

At the age of 15, boys and girls are in a period of rapid sexual development. It is an age that is characterised by confusion and need for counselling. With high levels of HIV infection in the region, it was interesting to see the level of eagerness in learning about reproductive health and behaviour. Cultural traditions tend to inhibit expression of eagerness to learn about reproductive matters. Learning about reproductive behaviour during adolescence has 'long-lasting effects on their future health and well-being' (Mensch, Bruce and Greene, 1998: 28). Table 3 shows the items grouped for the sub-construct 'Human reproduction'. It is noted that the alpha reliability value of 0.619 is smaller than the recommended 0.7 (Field, 2003; Pallant, 2001); although this is expected for a small number of items. The logical meaning of individual items is also a very good reason for grouping them together (Sjøberg and Schreiner, 2005). Gable and Wolfe (1993, in Schreiner and Sjøberg, 2004) observe that for attitudinal scales, an inter-item correlation of 0.3 to 0.4 is a good measure.

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**Table 3: Variable composing the factor Human reproduction**

<b>Composite variable: Human reproduction (Cronbach <math>\alpha</math> = 0.619)</b>	<b>Mean for girls</b>	<b>Mean for boys</b>	<b>Total mean</b>
A8. Heredity, and how genes influence how we develop	3.09	2.96	3.03
A9. Sex and reproduction	3.42	3.50	3.45
A10. Birth control and contraception	3.25	2.97	3.13
A11. How babies grow and mature	3.32	2.98	3.17
E31. Biological and human aspects of abortion	3.40	3.11	3.27

Reproductive education is critical to adolescents in Zimbabwe; especially because it has 24.6% HIV prevalence (UNDP, 2005). Rapid urbanisation, poverty, ignorance about reproductive rights and behaviours, breakdown of family structures and inadequacy of counselling services all contribute to pre- and extramarital sexual activity. Reproductive health education therefore has significant relevance for life. A Department for International Development (DFID) report on Zimbabwe (DFID, 2005: 1) had the following to say about maternal mortality:

... the maternal mortality ratio has increased at an alarming rate from 283/100,000 in 1994 to an estimated 1,100/100,000 in 2005 (UNICEF, 2005), which is a long way off from the Millennium Development Goal (MDG) target of 174.

These statistics are indicative of a dire need for reproductive education, among other things. The cheapest and most directly accessible intervention to this problem (which includes 15-year-old girls) is an education that gives life skills in handling personal reproductive behaviour. Parents are their children's primary educators, but, given the breakdown of family structures, the emergence of child-headed families, and economic hardship, the function traditionally played by parents needs to be taken over by schools. Many are quite ignorant of reproductive health needs and carry dangerous misconceptions about HIV. While the data cannot tell us why children are interested in reproductive health issues, their interest is a good precondition for their successful education.

Information and education about HIV is 'the first line of defence' (UNAIDS, 2004). Linking knowledge about diseases to personal behaviour

is still a problem in Zimbabwe and other sub-Saharan African countries, as figures show that 'only 8% of out-of-school youth and slightly more in-school youth have access to prevention education' (UNAIDS, 2004: 95). The urgency of the problem cannot be overemphasised.

### **Factor 2: Information and communication technologies (ICTs)**

Interest items relating to ICTs factored as one composite variable (see Table 4). The inter-item correlations and Cronbach alpha reliability values are in a good range. All children in Zimbabwe show a very high interest in ICTs. For all the items in this composite variable, children's experience is mainly found outside school science. While there may be reference to devices and systems in ICTs, these are not adequately covered in the curriculum.

Zimbabwean children's interest in ICTs may be motivated by the curiosity to know about rapidly changing technologies such as cellular phones and the internet. ICT influences social habits, drives tastes and has undoubted positive economic impact. In developed countries, the youth comprise the largest and fastest growing market for cellular phones, often for very practical reasons (Selian and Srivastava, 2004).

Computers, Internet and mobile phones command great interest among young people, despite the fact that they are beyond the reach of many children. In Harare, the number of Internet service providers increased from 6 to 27 in just two years (IWS, 2005). The number of Internet cafés has also increased rapidly and are they are generally oversubscribed. This can be attributed to 'a desire by mainly the young generation to access the Internet for educational, communication and entertainment reasons' (IWS, 2005: 1) However, while there may be high interest levels, availability of the infrastructure, hardware and services, and Internet café charges are some inhibitions to the full expression of that interest.

Most children have little or no formal teaching in computer-based skills in their schools because there are simply no computers. More children benefit more from having books to read than having expensive computers that also require a costly level of infrastructure to optimise their utility. Here exists developmental dilemma in which a relevant technological innovation overtakes the readiness of a nation. Donations and investments in computer technology appear urgent, and yet the nation still has to deploy resources for more primary needs such as reading and writing materials. It is a sad state of affairs where children are eager to learn and computers are made available (through generous donations), but there is no electricity in

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**Table 4: Reliability statistics for composite variable ICTs**

Composite variable: ICTs (Cronbach $\alpha = 0.792$ )	Mean for girls	Mean for boys	Total mean
C3. The use of lasers for technical purposes (CD-players, bar-code readers, etc.)	2.96	3.47	3.20
C4. How cassette tapes, CDs and DVDs store and play sound and music	3.28	3.50	3.38
C5. How things like radios and televisions work	3.14	3.51	3.31
C6. How mobile phones can send and receive messages	3.34	3.53	3.43
C7. How computers work	3.61	3.65	3.63
A45. The use of satellites for communication and other purposes	2.88	3.21	3.03

the school or there is no teacher capable of teaching computer skills, or both. Often there is no shortage of eagerness on the part of children, but poverty is a known limitation to maximal educational growth.

**Figure 1: Graph of interest in ICTs as expressed by the Zimbabwean sample**

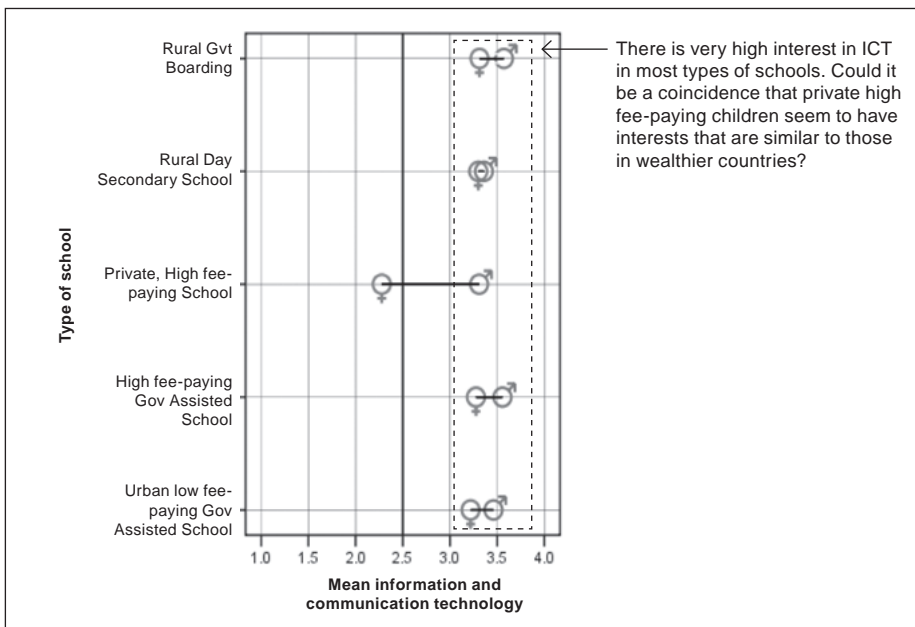
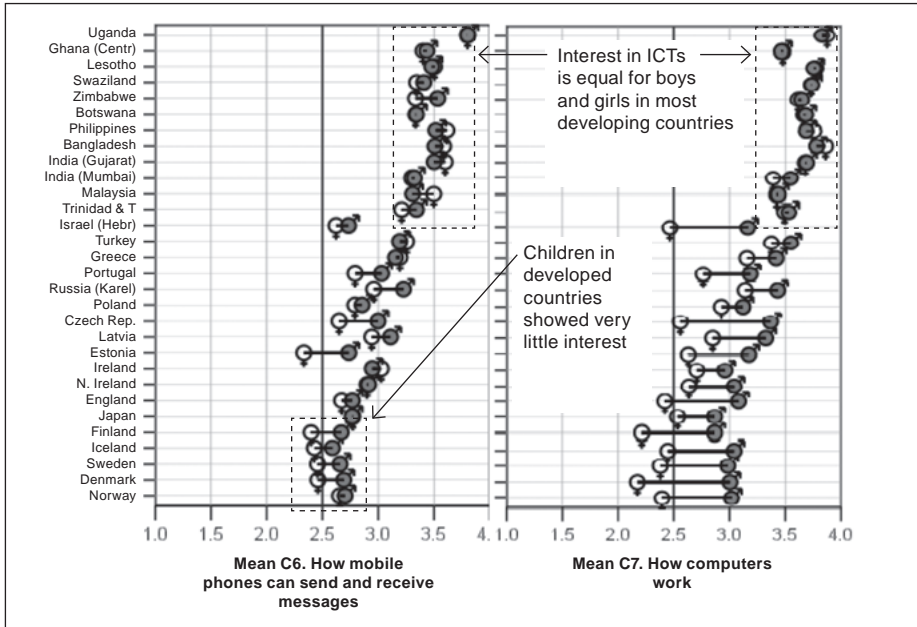


Figure 2: Comparative worldwide responses to items about ICTs



The higher interest in ICTs by boys for all countries is very prevalent. It is, however, quite interesting to note that despite the fact that Sweden and Finland are giants in the mobile phone industry (manufacturers of Ericsson and Nokia), the children there showed far less interest than non-producers of this technology (the non-Europeans at the top of graph). In June 2001, Finland and Sweden had 76.4 and 74.6 mobile phones per 100 inhabitants, respectively (Statistics Finland, 2001). It is possible that for these two countries and for Japan that the high level of availability of ICTs makes it common to children that they do not have as much excitement about them as compared to children in less developed economies where cellular phones are expensive and regarded as luxury possessions.

However, the interests expressed is not encouraged while children are in school because the school curriculum does not make any real reference to current ICT innovations. The Zimbabwe O-Level science syllabus (2003) has nothing about the modern technology principles and technologies that are practical in their lives. For a better public understanding of current technology, school science needs to change more rapidly to include contemporary issues in science, society and technology.

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### **Factor 3: Disease and human health**

Every child in Zimbabwe has been affected by HIV/AIDS or other debilitating diseases like malaria and tuberculosis. The loss of a relative (sometimes several immediate family members) or a member of the wider community detracts from the richness of each child's life. Teachers, relatives and friends have either died, been away sick for long periods or have been drawn away from daily activities to attend to health- and death-related issues. The overall effect is a considerable threat to the quality of life. For this reason, health matters are of principal interest to children.

The composite variable for human health is made up of six items (see Table 5). The items have high inter-item correlation for attitudinal items. Boys and girls show very strong interest in health issues. All the aggregated items (except E.10) are interconnected with HIV/AIDS. The highest infection rates are found in the age range starting from 15 years and it is known that girls become sexually active before boys of the same age (SAHIMS, 2004). It is therefore probable that there were sexually active girls among the children who answered the questionnaire. Their awareness of the existence of an epidemic and a positive desire to study and control the disease is a necessary outcome for the long-term fight against disease. A good proportion of the diseases could be prevented by healthy habits. In this context, science education commands an adequate level of interest in secondary schoolchildren, which is a natural opportunity to influence and change attitudes and fight epidemics with a new mindset (PCET, 1999).

**Table 5. Items addressing disease and human health issues affecting their country**

<b>Composite variable: Disease and human health (<math>\alpha = 0.763</math>)</b>	<b>Mean for girls</b>	<b>Mean for boys</b>	<b>Total mean</b>
E7. How to control epidemics and diseases	3.53	3.43	3.48
E8. Cancer, what we know and how we can treat it	3.57	3.43	3.51
E9. Sexually transmitted diseases and how to be protected against them	3.73	3.59	3.66
E10. How to perform first aid and use basic medical equipment	3.55	3.42	3.49
E11. What we know about HIV/AIDS and how to control it	3.63	3.55	3.59

E12. How alcohol and tobacco might affect the body	3.47	3.42	3.45
A26. Epidemics and diseases causing large losses of life	3.28	3.13	3.21

### **Children's interests in science classes**

Table 6 shows composite variables constructed from the items enquiring about children's views on their science lessons. Comparison of interest in science as a subject for international survey shows a very encouraging outcome for Zimbabwe. There is substantial evidence about the positive impact science classes have on attitudes. The challenge remains in providing enabling educational circumstances to transform these attitudes into practical development.

### **Gender equity in science and technology education**

The ROSE survey shows equal interest and positive attitudes for boys and girls in considering their experiences in science classes (see Table 6). Cronbach alpha values for the composite variables are very high and show internal consistency of the composite variables. Data from other countries (Figure 3), shows that girls in countries with high human development indices dislike science subjects. The poor showing of girls in the technical and science subjects is a likely indicator that there are either features in the education system that do not enable as many girls to pursue these technical studies or that the girls themselves do not choose technical areas.

The items preferred by girls are more inclined to concern human life, personal beauty, aesthetic value and the paranormal. Boys' interests, on the other hand, are generally technically biased. This underscores the dimension of preferences in the gender equity debate in science and technology. Sturman (1997) noted that in Australia, males are more likely to enrol in the physical sciences and technical studies while females are more likely to enrol in languages. Therefore, while there are several other factors that may explain differences between boys and girls, the ROSE survey brings the affective dimension to explain the disparity between boys and girls. The point is not necessarily to make boys and girls equal, but rather to give equal opportunity to those who choose to study in technical areas. Thus, gender balance in studying science is not a game of balancing numbers, but is rather about ensuring equal access to learners

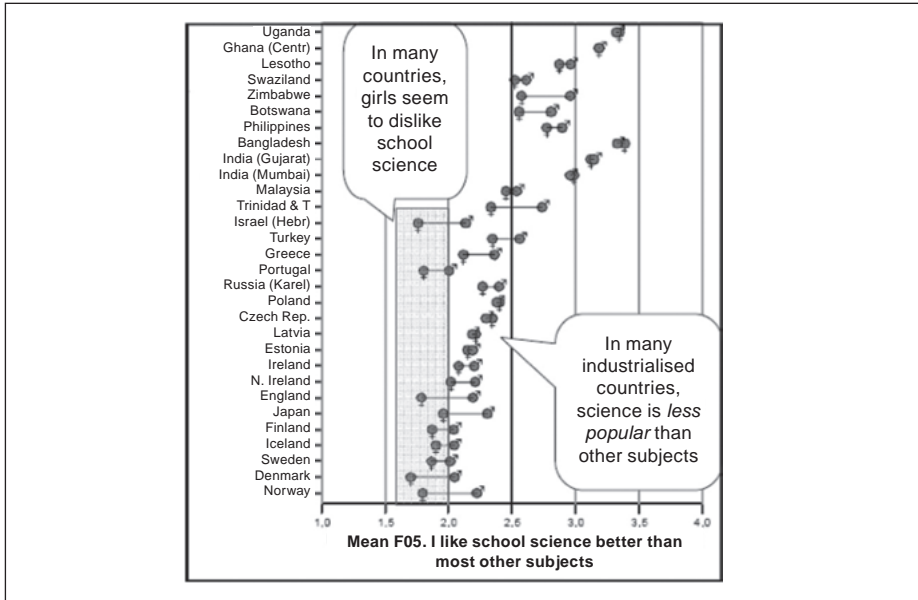
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to study what is relevant. The attitudes of Zimbabwean girls to science classes is, however, quite different from those in developed countries. Low participation by girls in science education is apparently not related to their interests at the age of 15. Other factors outside the scope of the ROSE survey are likely to be responsible for low enrolment figures for girls.

**Table 6: Composite variables for children's views about their science classes and mean scores for the composite variables**

<b>Composite variable</b>	<b>Combined items from Section F of ROSE questionnaire (My science classes)</b>	<b>Cronbach's <math>\alpha</math></b>	<b>Mean for boys</b>	<b>Mean for girls</b>
Desire to study science	2. School science is interesting 5. I like school science better than most other subjects 6. I think everybody should learn science at school 15. I would like to have as much science as possible at school	0.713	3.1	3.3
School science is important for everyday life	7. The things that I learn in science at school will be helpful in my everyday life 8. I think that the science I learn at school will improve my career chances 12. School science has shown me the importance of science for our way of living 13. School science has taught me how to take better care of my health	0.797	3.4	3.4
School science changed the way I look at the world	9. School science has made me more critical and sceptical 10. School science has increased my curiosity about things we cannot yet explain 11. School science has increased my appreciation of nature	0.651	3.2	3.2
Career opportunities in science	4. School science has opened my eyes to new and exciting jobs 14. I would like to become a scientist 16. I would like to get a job in technology	0.735	3.1	3.3

Figure 3: International survey results on desire for science subjects



## Discussion

The desire of all children to learn science is a very encouraging outcome from the Zimbabwe data. While there are limitations to access to science education as a result of many economic issues, several opportunities exist for science education in Zimbabwe. The most important outcome from the ROSE study is that schoolchildren have an intrinsic desire to learn about the issues around them. Interest is a principal forerunner of cognitive and psychomotor growth of children. Several items which the children show interest in are issues they experience in life out of school and are not directly dealt with in school. This has immediate implications for science education. One question that comes to mind is how well does the science curriculum cater for the interests of the child? Whose interests are catered for in the curriculum anyway? Inclusion of the children's interests in the curriculum has the immediate effect of making the curriculum more learner-centred. Commitment to learning science is likely to be more guaranteed when children find it assists them to understand and control their environment.

## *What Are the Interests of Zimbabwean Secondary School Children?*

In a recent study on the purposes of science (Osborne and Hennessy, 2003), a thematic approach to science education emerged where a wide range of issues is studied in order to give broader understanding of science. Given the strong interest in learning science, the children are making a statement about needing a change of focus to make science more relevant to their situation in Zimbabwe. It might just be that the time is right for science education to change in response to the needs and aspirations of the children.

Children's interests in science education are generally influenced by considerations of future employment, the enjoyment of science and availability of science education (see Table 6). The ROSE study outcome corroborates similar studies (Lord and Harland, 2000), showing the main motivation for studying science as the perceived hope for employment or other economic activity after school. While school science is one of the primary elements necessary for economic growth, there are other important contributory factors to be considered. Political, social and economic factors, as well as the natural environment, play critical determining roles in the availability of science education. To learners, science education may have its social, personal and subject purposes, but for the achievement of these, a progressive economic and political environment is required. The high interests shown by Zimbabwean children can also be understood as a natural response by children who are aware of the benefits of science education.

Based on the outcomes of the ROSE study in Zimbabwe, new and urgent requirements in science education become significant. One implication is the writing of beyond-the-curriculum materials that are designed to capture the interest of pupils. The dearth of reading materials for science is well known in many African countries. Any available resources are 'reasonably' spent on textbooks, which in many cases are heavily influenced by foreign texts. Zimbabwean children need a wider range of literature and sources of information to satisfy their thirst for knowledge. It is an urgent requirement for Zimbabweans to produce curriculum materials that present scientific concepts and skills in Zimbabwean contexts. Information about contemporary global issues that are critical to human life such as climate change and HIV/AIDS must be made more readily available to learners in school. This makes it necessary for school science to be seen in the global context. Global issues are of equal interest to children as local issues. Widening the exposure of secondary schoolchildren to issues and debates is likely to create more scientifically informed citizens.

One sharp criticism of Zimbabwean education came from the public submissions to the commission of enquiry on education and training (PCET, 1999). School-leavers were found to be unable to cope with life skills in the world of work. Noting that the children themselves have a high interest in science, there is need perhaps to ask: 'How learner-centred is the teaching of science in schools?' Besides addressing the teaching of science in schools, the planning of the science curriculum needs to have more deliberate research into methods and content structure which appeals to the youth, so that their interest in science may be sustained.

The Zimbabwe school examinations council recently started brainstorming on the theme 'Benchmarking ethno-based learning and school-based assessment in a multi-ethnic and multicultural environment' at the 2nd Regional Conference on Assessment 2004. One of the conference objectives was:

To provide a useful forum for researchers and examiners to share ideas for teaching, learning and assessment in a multi-ethnic and multicultural environment.

'Ethno-based learning' referred to identifying strategies to 'enable education to be practical and relevant so that children can closely relate their education to the real needs of their societies' (Zimbabwe School Examinations Council, 2004: 2). Among other strategies, this implies writing learning materials in a context that children can identify with and addressing scientific ideas within their experiences. The conference concurs here with ROSE studies that scientific ideas that appeal to children are in the context of their experiences. However, one would have wished a fuller spectrum of stakeholders to share ideas, including, among others, teachers and parents. Studies on the interests and aspirations of children are an essential and missing component in the exchange of ideas. The ROSE survey fills in a conceptual gap in the process of curriculum development and science teaching where practitioners need to listen to the children themselves and incorporate their voices. A drastic change in approach to teaching and writing educational materials, subject syllabuses and examinations is necessary to focus the practice of science education on the mindset of the children.

## Endnote

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# *18. The Relevance of School Mathematics Education (ROSME)*

Cyril Julie and Lorna Holtman

## **Abstract**

The contexts that learners deal with in contextually-based mathematical activities are mostly decided upon by designers and developers of mathematics curricula and learning resources and test developers. The voices of learners on the contexts they would prefer to deal with in mathematical activities are virtually absent in research. This chapter deals with the voices of learners and reports on a project which ascertained the contexts learners would prefer to deal with in mathematical education. The viability of a questionnaire to ascertain the interests of learners is discussed. Furthermore, the chapter reflects on the rankings assigned by learners from six different countries relative to the five highest and five lowest preferred items of the overall ranking of items.

## **Introduction**

The Relevance of School Mathematics Education (ROSME) is a multi-country project pursuing the following issue: What are the contextual situations learners in Grades 8 to 10 prefer to deal with in mathematics? The primary rationale and motivation for the project is linked to the current international objective that schools should graduate learners who are mathematically literate. Mathematical literacy deals primarily with the cultivation of a mathematical perspective on extra-mathematical issues and situations. These issues and situations are to a large extent determined by curriculum, learning resources and test designers. This chapter focuses on the contexts learners in six countries would prefer

to deal with in mathematics. In particular, it discusses the viability of the instrument developed to ascertain the contexts students would find relevant in mathematics. Furthermore, it compares and reflects on the rankings assigned by the different countries relative to the five highest and five lowest preferred items of the overall ranking of the items.

### **The use of context in school mathematics**

The contexts that learners prefer to handle in mathematics is a topic that is relatively under-researched. In this regard, trawling the Internet and an Education Resources Information Center (ERIC) database search using key sentences and phrases such as 'Contexts young people prefer for mathematics', 'Contexts pupils are interested to learn about in mathematics' and 'Students and contexts in mathematics' rendered zero hits. A wider search with the key phrase 'Contexts and mathematics' using the authoritative mathematics education database, MathDi, rendered 683 hits. However, the reported articles do not deal specifically with the contexts learners would prefer to deal with in mathematical literacy. Studies deal primarily with the effect of using contexts for mathematical concept formation, the effect of the use of contexts on learners' mathematical achievement, and the ability of learners to identify mathematics in everyday activities. For example, the work of Dapueto and Parenti (1999) deals with contexts and the formation of mathematical concepts. The study by De Bock et al. (2003) is representative of those ascertaining whether the use of contexts positively impacts on learner achievement in mathematics. The third kind of study is represented by a study conducted by Edwards and Ruthven (2003), who interviewed learners using pictures of five everyday English activities – dressmaking, Lego, chess, knitting and pool – with the purpose of ascertaining whether the learners could identify mathematics in everyday activities. Another set of studies dealt with issues related to the learners' handling of contexts in mathematics and the arguments for confronting learners with contextual situations. Regarding the first issue, for example, Busse and Kaiser (2003) investigated the transformations contextual problems undergo during the process of sense-making of the contexts by learners. They contend that these transformations, from an objective figurative one to a subjective figurative one, might enhance or hinder learners' engagement with contextual situations mathematically. The work by Lepper (1988) epitomises those works related to the arguments provided for the 'mathematics in context' approach. According to Lepper,

this approach to mathematics promotes intrinsic motivation. However, none of these approaches to the use of contextual situations in school mathematics deal explicitly with the contexts that learners prefer. There is thus a paucity of evidence-based knowledge about contexts that learners would prefer to deal with in mathematics.

Lesch (1980: 7) brings to the fore how teachers – and, by implication, others in the school mathematics enterprise concerned with learning resource development – can come up with contexts which learners might not find relevant by stating that ‘our [teachers’] ideas about the real world were somewhat different from our students’ ideas’ when designing and implementing contextually-based mathematical activities for students. D’Ambrosio, Boone and Harkness (2004) also draw attention to the paucity of the consideration of student voice in the design of activities for mathematics teaching and learning. Referring to their review of professional development programmes for mathematics teachers they state:

In all of these studies, the student voice was largely ignored in describing the state of mathematics instruction, whether locally, nationally, or internationally. In reviewing the research regarding the planning of professional development, there was also a striking absence of any work that included surveys of students and planning based on the reports of students regarding what happens in their day-to-day mathematics experiences. (2004: 6)

They conclude that ‘[in addition] to the voices of the district’s administration and the teachers in the district, the voices of the students can be used to shape professional development initiatives’ (2004: 15). The ROSME project is situated within the thrust in research in mathematics education which considers student voice an important issue in school mathematics curricula and other issues related to the school mathematics enterprise.

### **Methodology, instrumentation, sampling and data collection**

As with other large-scale multinational projects, survey research was used in this study. Data were collected using a questionnaire. This instrument was developed by a group of mathematics teachers and mathematics educators. Julie and Mbekwa (2005) described the development of the instrument. The study contains both intra-mathematical elements, dealing explicitly

with mathematics as a discipline and mathematical practices, and extra-mathematical elements, dealing explicitly with contexts and items. There are 50 extra-mathematical and 11 intra-mathematical items for which respondents had to express their preference on a four-point Likert-type scale with response category choices indicated by 'Not at all interested', 'A bit interested', 'Quite interested' and 'Very interested.' The questionnaire is given in Appendix A. The questionnaire was translated into the primary languages of South Korea and Norway, and an Afrikaans version of the questionnaire was used by Afrikaans-speaking students in South Africa.

Grade 8, 9 and 10 students were targeted since these grades normally coincide with the onset of junior secondary schooling, the end of compulsory schooling and the onset of the final three years of schooling. The demographic information of the six participating countries is indicated in Table 1.

The South Korean sample covered the entire country. The Norwegian sample was a particular school district in southern Norway. Students from poor socio-economic environments in the Western Cape province of South Africa were selected. In Swaziland the concentration was on high-performing urban schools. The Ugandan sample was entirely rural. Schools in rural and urban low-income areas were selected in Zimbabwe. The varying nature of the samples in different countries was mainly due to the access researchers had to schools and to the different locations, which was largely determined by constraints in financial resources.

Once the schools were selected, the sampling unit was a randomly selected school class or grade. Only one class per grade level at the selected school completed the questionnaire. Thus only one Grade 8, one Grade 9 and one Grade 10 class at a selected school completed the questionnaire.

Researchers and postgraduate students collected the data; except in Korea, where the data were collected by teachers after thorough briefing by a postgraduate student. This was done so that the data collectors could provide as much clarity to the respondents as possible.

Data were analysed using Rasch procedures. These procedures are recommended for rating scale analysis (Bond and Fox, 2001). Rating scales of the kind used in this study normally ignore the fact that the response categories are not necessarily linear in the sense that the distances between subsequent responses are not equal. Rasch procedures solve this problem by transforming the data so that the linearity issue is addressed. In Rasch modelling, a model is not sought to fit the obtained data. Instead, the

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Rasch model is taken as the ideal and the quest is to determine how closely the data fit the Rasch model. Various statistics are reported when Rasch analysis is used, and for this project these statistics were obtained using the Winsteps programme. The Rasch analysis procedures are not discussed in this chapter and the reader is referred to the references for further information regarding Rasch analysis of ordinal data (see Bond and Fox, 2001; Linacre, 2008; Reeves and Fayers, 2005).

**Table 1: Demographic information on the six ROSME-participating countries**

		Korea	Norway	South Africa	Swazi-land	Ugan-da	Zim-babwe	Total
Gender	Male	874	41	550	454	116	450	1 963
	Female	771	49	627	574	44	449	2 011
Grade	8	481		260	386	50	300	1 195
	9	384	90	526	335	45	300	1 441
	10	780		391	307	65	300	1 339
Age	12			19	6			25
	13	17		157	122	2	61	359
	14	79	70	328	208	11	195	891
	15	561	20	367	287	26	263	1 524
	16	343		198	186	35	264	1 026
	17	636		69	121	40	117	983
	18	7		19	26	16		68
	19			13	17	15		45
	20			6	3	7		16
	21				1	4		5
	22			1		1		2
	23							0
	24							0
25						1	1	
Location	Urban	523	90	475	1028		450	2 566
	Peri-Urban	628		702				1 330
	Rural	494				160	450	1 104

## Results and discussion related to the instrument

As explained in Julie and Mbekwa (2005), the ROSME items were developed based on their suitability for mathematical treatment and the collective consensus of a group of mathematics teachers and mathematics educators about the issues which do or don't interest young people. Furthermore, the contexts used in the research literature on context-driven mathematics also informed the identification of items as indicators of the construct of students' preference of contextual situations to be used in school mathematics. Thus, it was expected that students would respond more or less equally across the four response categories. The summing of the observed counts across response categories, presented in Table 2, indicate that this was more or less the case, with a close spread across the four response categories.

**Table 2: Distribution across response categories**

Response label	Observed count	Percentage
Strongly disagree	68 368	28
Disagree	65 367	26
Agree	57 011	23
Strongly agree	56 105	23

The hierarchical rankings of the items, with their logit values (the unit forthcoming from Rasch analysis) are presented in Table 3. They are in increasing order of context preference endorsement.

**Table 3: Hierarchical ordering of items**

Item	Total score	Count	Measure	Infit mean square	Outfit mean square
C36	9 985	4 921	0.46	0.89	0.84
C43	10 160	4 962	0.42	1.08	1.10
C32	10 333	4 921	0.42	0.88	0.85
C2	10 069	4 917	0.40	1.41	1.77
C37	10 304	4 925	0.37	0.99	0.98
C17	10 427	4 941	0.34	0.97	0.92
C1	10 550	4 949	0.32	1.22	1.42

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C31	10 525	4 950	0.31	0.95	0.89
C13	10 684	4 968	0.28	1.05	1.05
C14	10 721	4 966	0.28	0.93	0.88
C8	10 656	4 907	0.28	0.91	0.88
C10	10 642	4 920	0.27	1.02	0.98
C28	10 931	4 942	0.27	1.00	1.00
C59	10 938	4 951	0.26	0.85	0.81
C18	10 749	4 902	0.25	1.00	1.00
C56	11 021	4 968	0.24	0.95	0.92
C40	10 807	4 908	0.22	1.26	1.37
C25	11 121	4 965	0.20	0.95	0.96
C9	11 166	4 910	0.17	1.00	0.98
C61	11 288	4 957	0.16	0.99	1.00
C30	11 228	4 933	0.15	1.15	1.22
C60	11 357	4 953	0.14	0.87	0.84
C5	11 443	4 946	0.11	1.01	0.98
C38	11 434	4 945	0.10	1.05	1.06
C19	11 704	4 928	0.05	0.96	0.95
C51	11 589	4 923	0.05	1.19	1.22
C41	11 700	4 930	0.03	1.03	1.04
C44	11 885	4 936	0.00	0.90	0.89
C12	12 089	4 964	-0.02	0.99	0.98
C54	11 940	4 930	-0.02	0.91	0.89
C49	12 031	4 938	-0.03	0.82	0.78
C52	11 851	4 842	-0.05	0.94	0.92
C39	12 243	4 924	-0.09	0.84	0.81
C7	12 479	4 928	-0.14	1.00	1.04
C24	12 804	4 967	-0.21	0.94	0.92
C57	12 823	4 954	-0.22	1.06	1.07
C21	12 883	4 958	-0.23	0.86	0.84
C42	12 910	4 932	-0.24	1.09	1.10
C50	12 941	4 946	-0.24	0.98	0.96
C48	13 143	4 923	-0.32	1.12	1.15
C22	13 272	4 946	-0.33	0.89	0.87
C58	13 298	4 948	-0.35	1.00	1.00
C16	13 388	4 950	-0.37	0.95	0.95

C20	13 417	4 935	-0.39	1.16	1.19
C35	13 429	4 917	-0.39	1.09	1.08
C47	13 764	4 916	-0.40	0.88	0.86
C11	14 570	4 942	-0.55	0.95	0.93
C3	14 191	4 929	-0.55	1.13	1.22
C46	14 699	4 949	-0.70	1.08	1.09
C15	14 976	4 969	-0.73	0.99	0.98
MEAN	11 891.20	4 937.00	0.00	1.00	1.01
S.D.	1 308.30	22.60	0.31	0.12	0.17

The range for the item difficulty measures (0.46 logits to  $-0.73$  logits in the column marked 'measure' in Table 3) fall within the range (2 logits to  $-2$  logits) for a scale constructed according to Rasch modelling (Reeve and Fayers, 2005). Linacre (2008: 221) states that a mean-square (MNSQ) infit statistic 'substantially less than 1 indicates dependency in your data' and a MNSQ outfit statistic is 'more sensitive to unexpected behavior by persons on items far from the person's measure level'. Infit and outfit MNSQ values in the range 0.5–1.5 is deemed to be 'productive of measurement' (Linacre, 2008: 221). Table 3 indicates that one item (C2: Outfit MNSQ = 1.77) falls outside of this range for the outfit MNSQ measure. The outfit MNSQ of 1.77, however, is less than 2 and is indicative of 'noticeable off-variable noise [which] neither constructs nor degrades measurement' (Linacre, 2008: 221). The instrument to ascertain students' context preferences for use in mathematics is thus well within the range of acceptable values and is acceptable as a scale constructed according to Rasch modelling.

The five most preferred contexts are: C3 (Mathematics involved in making computer games such as play stations and TV games.), C11 (Mathematics that is relevant to professionals such as engineers, lawyers and accountants), C15 (Mathematics involved in secret codes such as pin numbers used for withdrawing money from an ATM), C46 (Mathematics involved in sending of messages by SMS, cellphones and e-mails) and C47 (Mathematics involved in working out financial plans for profit-making.) Three (C3, C15 and C46) of the highest preferred contexts fall in what can be broadly termed as modern technology; one (C11) is linked to high-status professions; and one to business/entrepreneurial activity (C47).

The five least preferred items are: C2 (Mathematics of a lottery and gambling), C32 (Mathematics involved in assigning people to tasks when a set of different tasks must be completed), C36 (Mathematics involved in

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working out the best arrangement for planting seeds), C37 (Mathematics to determine the number of fish in a lake, river or a certain section of the sea) and C43 (Mathematics linked to decorations such as the house decorations made by Ndebele women). These items are varied and not as easily grouped as the most preferred items. They span broader issues such as agriculture (C36), environmental issues and sustainability (C37), ethnomathematics (C43), productivity (C32) and societal behaviour (C2).

Figure 1 presents the person-item map for this cohort of students. The first observation resulting from the inspection of this map is the difference of the means for persons (left-hand side) and items (right-hand side). This suggests that the instrument mis-targeted the students in this study in that the items were found difficult by the students to endorse.

Also evident from Figure 1 is that 41 of the 50 context preference items share the same location on the logit scale with at least one other item. This indicates redundancy of items and, depending on the latent trait under consideration, points to the replacement of items at that location by just one of the items without having an effect on the reliability and validity of the instrument. However, the construct under consideration in this study is such that items might have a similar location on the scale, but be conceptually different in that they refer to distinctly different contexts. Ten of the items that share the same location at one standard deviation from the mean are indicated in Table 4.

It is clear that the items can be classified into different contextual domains: two (C10 and C31) are in the domain of elections, three (C14, C17 and C8) are agricultural in nature, two (C13 and C28) are related to transportation, and the domains of the remaining ones are economics (C18), youth culture (C40) and environmental issues (C56). Given this observation of items belonging to different larger contextual domains sharing the same location, the potential exists for reducing the number of items by only including a single item to capture the larger domain in the next development stage of the instrument.

The person-item map also indicates that there are no gaps in the spread of items. This shows that there are no 'poorly defined or tested regions of the variable [and the] items targeted (lined up with) the persons' (Linacre, 2008: 206).

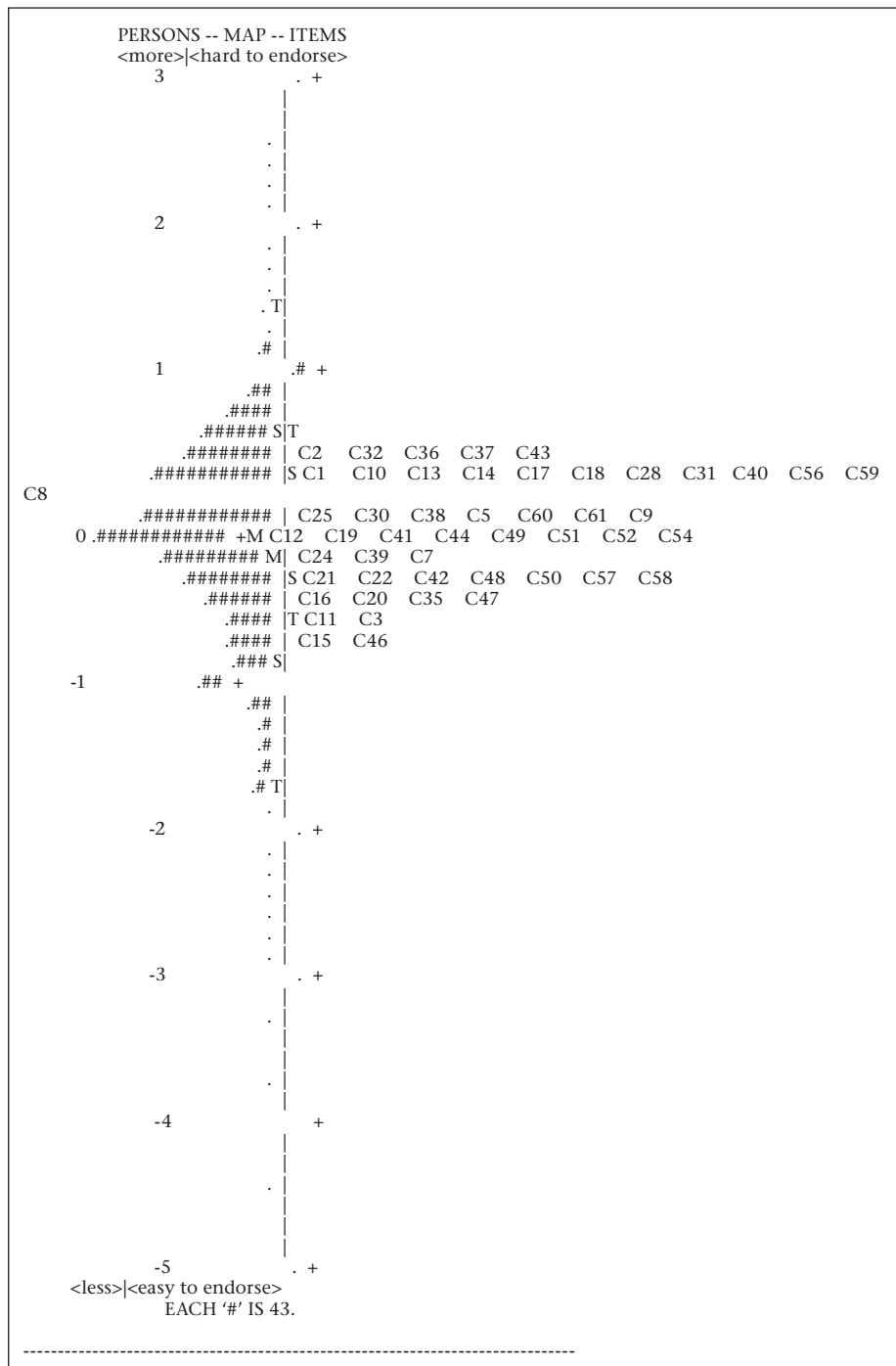
**Table 4: Set of items on the same location on item-map**

Item	Context	Class
C10	Mathematics political parties use for election purposes	Politics
C13	Mathematics involved in designing delivery routes of goods, such as delivering bread from a bakery to the shops	Transportation
C14	Mathematics needed to work out the amount of fertilizer needed to grow a certain crop	Agriculture
C17	Mathematics involved for deciding the number of cattle, sheep or reindeer to graze in a field of a certain size	Agriculture
C18	Mathematics of inflation	Economics
C28	Mathematics involved in packing goods to use space efficiently	Transportation
C31	Mathematics used to calculate the number of seats for parliament given to political parties after elections	Politics
C40	Mathematics linked to rave and disco dance patterns	Youth culture
C56	Mathematics to describe facts about diminishing rain forests and growing deserts	Environmental
C8	How to estimate and project crop production	Agriculture

### Comparison of countries relative to the overall rankings

In large-scale international tests such as the Trends in International Mathematics and Science Study (TIMSS) the performance of countries is ranked according to their mean score and comparisons are done relative to the overall mean score of all participating countries. For ordinal data it does not make sense to speak about something like a mean performance. Rather, the ranking positions assigned to different items can be compared and, if deemed appropriate, significance of these assigned rankings can be done using non-parametric statistical procedures. In what follows, only the differences in ranking positions relative to the five highest and five lowest overall ranking of items are considered and discussed. Only those items among the five highest and five lowest overall in at least three countries are discussed. Table 5 presents the ranking of the items (in ascending order of endorsement) of the six countries and the overall ranking of the items.

Figure 1: Item map



**Table 5: Rankings of items by country and overall ranking**

Korea	Norway	South Africa	Swazi-land	Uganda	Zim-babwe	Overall	Ranking
C31	C31	C2	C37	C40	C2	C36	50
C14	C36	C17	C43	C43	C43	C43	49
C36	C10	C14	C40	C38	C40	C32	48
C17	C8	C36	C2	C2	C1	C2	47
C32	C14	C43	C36	C51	C30	C37	46
C8	C37	C28	C1	C20	C37	C17	45
C59	C13	C13	C13	C30	C51	C1	44
C10	C59	C8	C32	C32	C32	C31	43
C13	C38	C10	C28	C56	C5	C13	42
C18	C17	C37	C18	C9	C56	C14	41
C60	C21	C1	C30	C18	C9	C8	40
C5	C54	C31	C51	C1	C25	C10	39
C39	C32	C56	C56	C42	C10	C28	38
C37	C60	C59	C25	C24	C28	C59	37
C49	C19	C32	C61	C5	C41	C18	36
C21	C28	C25	C9	C61	C19	C56	35
C25	C43	C41	C17	C12	C57	C40	34
C11	C41	C18	C10	C41	C36	C25	33
C38	C5	C60	C31	C44	C12	C9	32
C61	C40	C40	C14	C54	C61	C61	31
C47	C22	C9	C19	C19	C59	C30	30
C9	C1	C30	C59	C48	C38	C60	29
C56	C25	C61	C38	C37	C31	C5	28
C28	C56	C57	C5	C60	C18	C38	27
C1	C16	C19	C8	C59	C8	C19	26
C44	C7	C38	C60	C13	C42	C51	25
C7	C9	C7	C41	C21	C54	C41	24
C43	C51	C49	C12	C35	C20	C44	23
C54	C39	C51	C7	C52	C44	C12	22
C16	C50	C54	C52	C10	C60	C54	21
C52	C44	C50	C54	C8	C24	C49	20
C22	C35	C48	C44	C46	C17	C52	19

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C12	C49	C39	C49	C25	C13	C39	18
C19	C30	C44	C42	C31	C52	C7	17
C30	C11	C52	C48	C39	C49	C24	16
C50	C61	C58	C24	C28	C14	C57	15
C24	C18	C5	C20	C57	C48	C21	14
C2	C12	C35	C39	C14	C35	C42	13
C41	C20	C42	C35	C17	C21	C50	12
C40	C57	C20	C50	C49	C22	C48	11
C51	C2	C12	C57	C36	C39	C22	10
C58	C47	C24	C58	C50	C58	C58	9
C42	C15	C21	C3	C58	C7	C16	8
C3	C24	C16	C16	C22	C50	C20	7
C57	C52	C22	C46	C7	C16	C35	6
C48	C58	C46	C22	C16	C15	C47	5
C35	C46	C3	C21	C11	C3	C11	4
C15	C48	C47	C15	C3	C46	C3	3
C46	C3	C15	C47	C47	C47	C46	2
C20	C42	C11	C11	C15	C11	C15	1

**The five least preferred items**

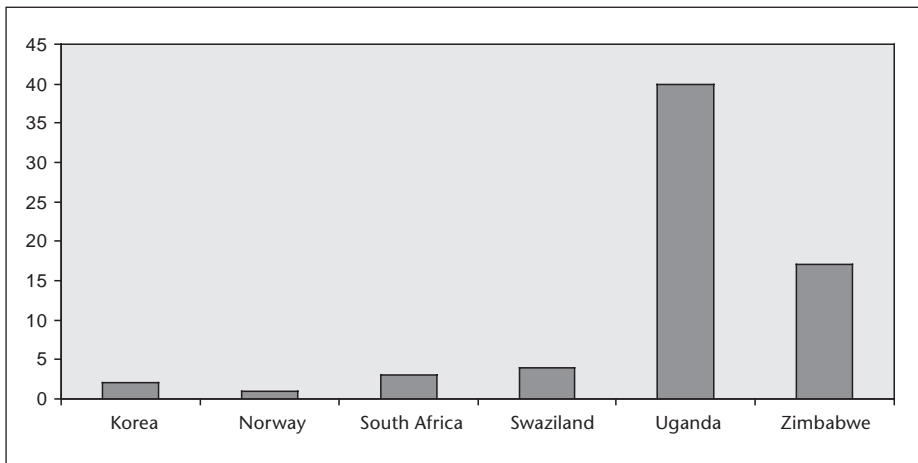
Item C36 (Mathematics involved in working out the best arrangement for planting seeds) is accorded a low preference by all except Uganda and Zimbabwe, as is evident in Figure 2. Figure 2 indicates the number of ranking positions this item is from the overall ranking position – i.e. position 50. (In the graphs that follow, the overall position ranking of the item is taken and the graph indicates the number of ranking positions the specific country is below or above this overall ranking position. For example, the overall ranking for C36 = 50, while Korea's ranking = 48. Korea is therefore two ranking positions above the overall ranking.) The medium to high preference (rank position 10 for Uganda and 33 for Zimbabwe, respectively) for these two countries might be linked to the inclusion of rural cohorts in these samples. The item deals with agriculture and points to young adults being not generally interested in agricultural matters.

A surprising issue is the low preference accorded to item 43 (Mathematics linked to decorations such as the house decorations made by Ndebele women, which was *particularised for different countries*) by the respondents from the four sub-Saharan countries (Figure 3). This item deals with the mathematisation of cultural artefacts, and hence with indigenous knowledge and ethnomathematics. This area of research in mathematics and mathematics education has its origin in developing environments (see D'Ambrosio, 1985; Gerdes, 1994). The expectation is that ideas and activities from an ethnomathematical perspective would have filtered down to the classroom level. Even though this might be the case, young schoolgoing adults in sub-Saharan Africa do not, as yet, perceive this as relevant in their mathematics.

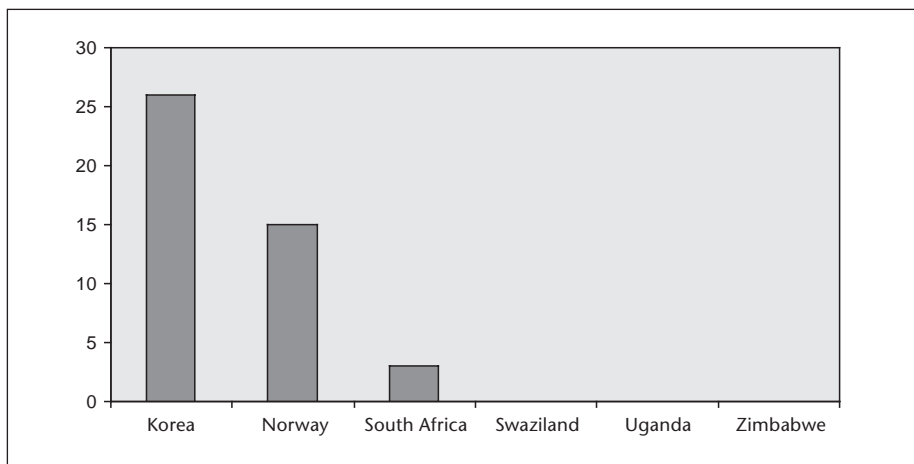
The rankings of South Korea and Norway for this item are 20 and 15 positions away, respectively, from the overall ranking, and this suggests a curiosity of these students in wanting to learn about the mathematisation of cultural artifacts.

Item C2 (Mathematics of a lottery and gambling) appears among the five least preferred items for the four sub-Saharan countries and is not among those for the two countries, Norway and South Korea, which occupy high rankings on the Human Development Index (HDI) of the United Nations (Figure 4). The South Korean and Norwegian cohorts' preference for this item (ranking positions 13 and 10, respectively) is much nearer to the strongly endorse end of the scale. Various debatable reasons can be offered

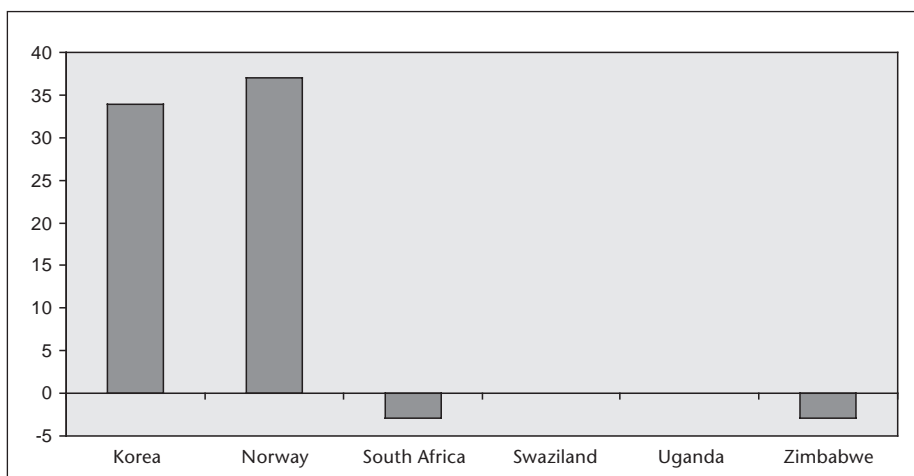
**Figure 2: Ranking positions relative to the global ranking for item C36**



**Figure 3: Ranking positions relative to the global ranking for item C43**



**Figure 4: Ranking positions relative to the global ranking for item C2**



for this phenomenon. Plausible ones are that in late-developing countries young adults are more aware of the negative consequences of spending money on issues dealing with randomness and that households in these environments simply do not have the financial resources to spend on recreational activities such as gambling, despite the high media visibility of rags-to-riches stories related to national lotteries (such as is the case in South Africa).

### The five most preferred items

The number of ranking positions away from the highest overall ranked item – C15 (Mathematics involved in secret codes such as pin numbers used for withdrawing money from an ATM) – is presented in Figure 5. This item deals with modern technology and appears among the five most highly ranked items for all the countries except Norway, where it is ranked position 8. This brings to the fore the interest young adults (independent of the development status of their country) have in technological matters.

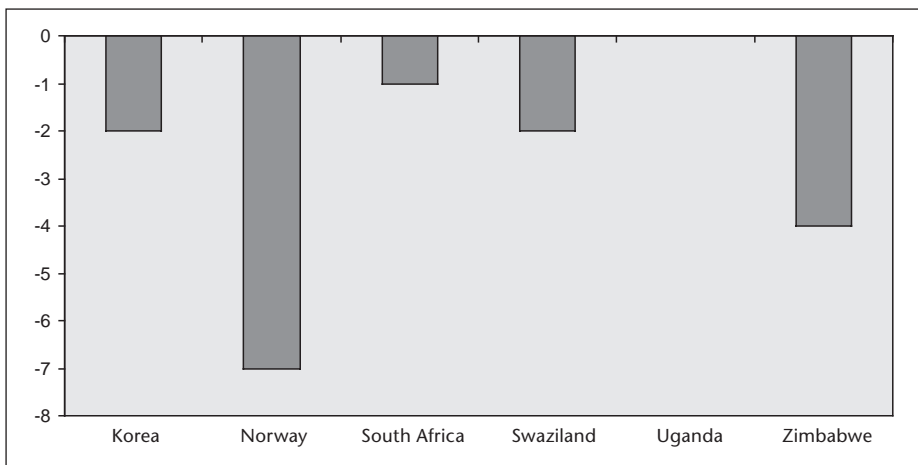
Four of the six countries selected item C46 (Mathematics involved in sending of messages by SMS, cellphones and e-mails) among their five most preferred items (Figure 6). Students from Uganda and Swaziland ranked the item in positions 19 and 6, respectively. The dominance of interest in modern technological matters is strengthened by the high preference accorded to this item.

Item C3 (Mathematics involved in making computer games such as play stations and TV games) was highly preferred by students in all the countries, except those from Swaziland (ranked eighth) and Korea (ranked seventh), as is evident from Figure 7.

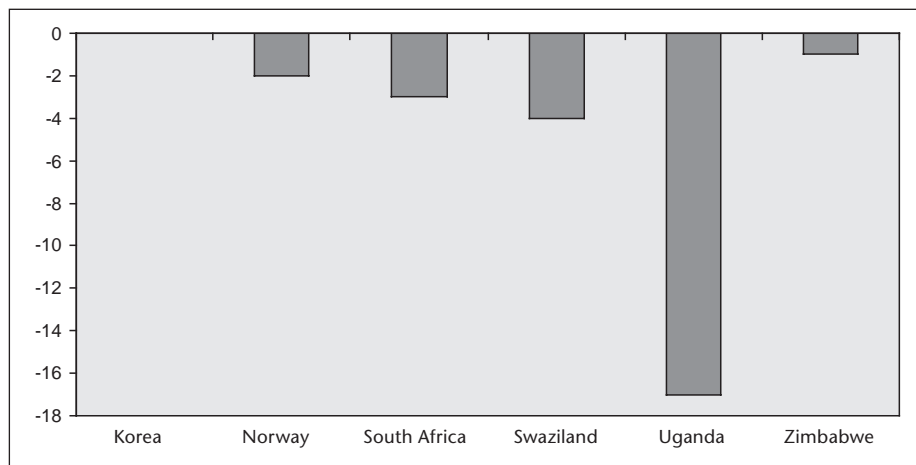
The item deals with modern technological recreational gadgets and interest in dealing with the mathematisation of such issues has high currency in both developed and late-developing environments.

Respondents from the four late-developing countries ranked item C11 (Mathematics that is relevant to professionals such as engineers, lawyers

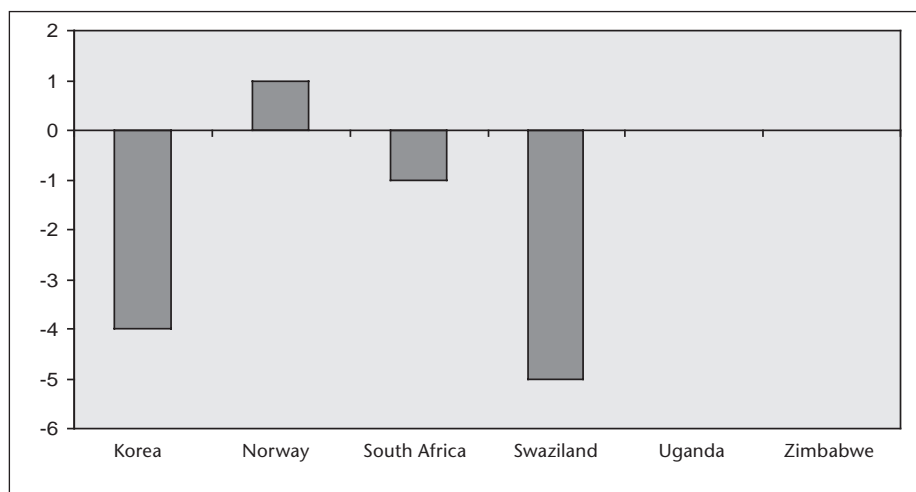
Figure 5: Ranking positions relative to the global ranking for item C15



**Figure 6: Ranking positions relative to the global ranking for item C46**



**Figure 7: Ranking positions relative to the global ranking for item C3**



and accountants) among their five highest preferred items. These are high-status professions in these countries and the desire of young people for such knowledge is brought to the fore. This is not necessarily the case for the two highly developed countries (Figure 8).

Figure 8: Ranking positions relative to the global ranking for item C11

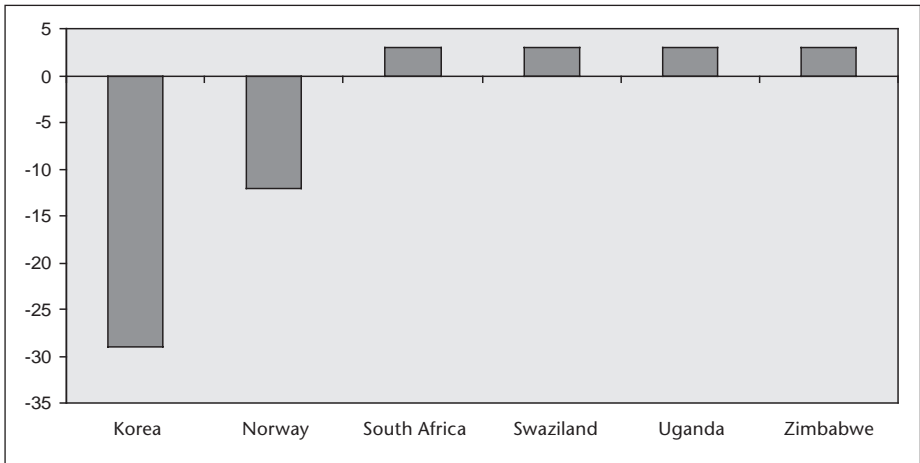
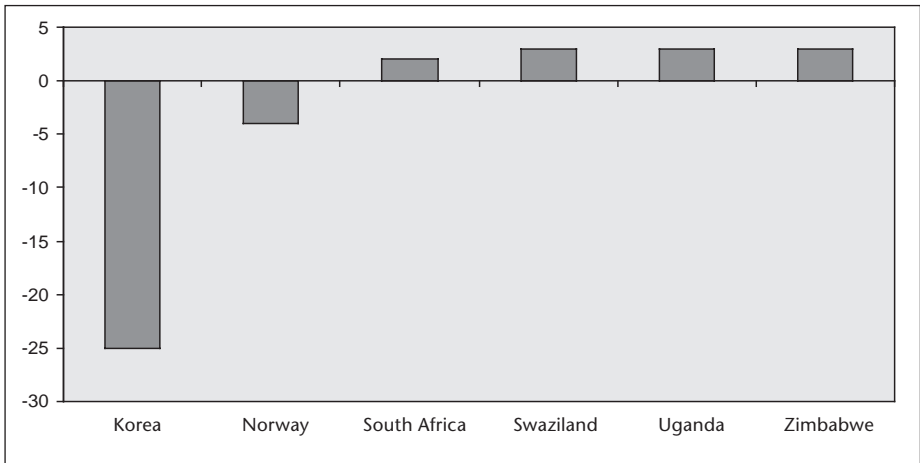


Figure 9: Ranking positions relative to the global ranking for item C47



Item C47 (Mathematics involved in working out financial plans for profit-making) is among the five highest preferred items for students from all four sub-Saharan countries and is not among those of the two developed countries. Since this item deals with financial matters, it is conjectured that it is closely linked to the developmental status of the sub-Saharan countries and awareness among students from these countries that the improvement of their economic capital will be linked to their own entrepreneurial initiatives. Figure 9 presents the number of ranking positions away from the overall ranking of item C47.

## **Conclusion**

A point of departure of the ROSME project is the necessity of getting a sense of student voice in mathematics curriculum matters. This is especially needed when dealing with contextual situations in school mathematics, since students can have differing emotional, motivational and value attachments to such contextual situations. Of particular concern is that students' preference for contextual situations to be used in school mathematics might be different from those favoured by curriculum developers and designers of learning resources. The results above indicate that there are similarities and differences of students' preferences for contexts to be used in school mathematics and some of these are related particularly to the developmental status of the country. It is suggested that the incorporation of contextual preferences of students in school mathematics might positively impact on their attitudes towards mathematics. A caveat, however, is necessary, and, as Skovsmose (1998: 419) asserts: 'It is essential to consider students' interest. But the interest cannot solely be examined in terms of the background of the students. Equally important is the *foreground* of the students.' This foregrounding relates to those which learners do not as yet perceive as interesting and, since schooling is also about the generation of interest, this should also be catered for in school mathematics curricula. Thus, as Julie (2007) argues, school mathematics cannot be solely driven by the interest of students. However, given that students do have interests whose incorporation in the mathematics curriculum might have positive consequences, a school mathematics curriculum where the contextual interests of students, teachers, parents and designers of curriculum and learning resources are balanced is called for.

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**APPENDIX**

CODE: \_\_\_\_\_

**RELEVANCE OF SCHOOL MATHEMATICS EDUCATION (ROSME)  
January 2005**

**Things I'd like to learn about in Mathematics**

I am:     a female     a male                    I am \_\_\_\_\_ years old

I am in Grade \_\_\_\_\_

What would you like to learn about in mathematics? Some possible things are in the list below. Beside each item in the list, circle only one of the numbers in the boxes to say how much you are interested. Please respond to all the items.

- 1 = Not at all interested
- 2 = A bit interested
- 3 = Quite interested
- 4 = Very interested

There are no correct answers: we want you to tell us what you like.

For office use	Things I'd like to learn about in Mathematics	Not at all interested	A bit interested	Quite interested	Very interested
C1	Mathematics linked to designer clothes and shoes	1	2	3	4
C2	Mathematics of a lottery and gambling	1	2	3	4
C3	Mathematics involved in making computer games such as play stations and TV games	1	2	3	4
C4	Why mathematicians sometimes disagree	1	2	3	4
C5	Mathematics used to predict the growth and decline of epidemics such as AIDS; tuberculosis and cholera	1	2	3	4

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C6	The personal life stories of famous mathematicians	1	2	3	4
C7	Mathematics used in making aeroplanes and rockets	1	2	3	4
C8	How to estimate and project crop production	1	2	3	4
C9	Mathematics to predict whether certain species of animals are on the brink of extinction	1	2	3	4
C10	Mathematics political parties use for election purposes	1	2	3	4
C11	Mathematics that is relevant to professionals such as engineers, lawyers and accountants	1	2	3	4
C12	How mathematics is used to predict the spread of diseases caused by weapons of mass destruction such as chemical, biological and nuclear weapons	1	2	3	4
C13	Mathematics involved in designing delivery routes of goods such as delivering bread from a bakery to the shops	1	2	3	4
C14	Mathematics needed to work out the amount of fertilizer needed to grow a certain crop	1	2	3	4
C15	Mathematics involved in secret codes such as pin numbers used for withdrawing money from an ATM	1	2	3	4
C16	Mathematics used to calculate the taxes people and companies must pay to the government	1	2	3	4
C17	Mathematics involved for deciding the number of cattle, sheep or reindeer to graze in a field of a certain size	1	2	3	4
C18	Mathematics of inflation	1	2	3	4
C19	Mathematics about renewable energy sources such as wind and solar power	1	2	3	4
C20	Mathematics involved in determining the state of health of a person	1	2	3	4
C21	Mathematics to assist in the determination of the level of development regarding employment, education and poverty of my community	1	2	3	4

*Julie and Holtman*

C22	Mathematics to prescribe the amount of medicine a sick person must take	1	2	3	4
C23	Mathematics that will help me to do mathematics at universities and technikons	1	2	3	4
C24	Mathematics involved in the placement of emergency services such as police stations, fire brigades and ambulance stations so that they can reach emergency spots in the shortest possible time	1	2	3	4
C25	Mathematics involved in making complex structures such as bridges	1	2	3	4
C26	The kind of work mathematicians do	1	2	3	4
C27	Geometry	1	2	3	4
C28	Mathematics involved in packing goods to use space efficiently	1	2	3	4
C29	How mathematicians make their discoveries	1	2	3	4
C30	Mathematics linked to South African pop music	1	2	3	4
C31	Mathematics used to calculate the number of seats for parliament given to political parties after elections	1	2	3	4
C32	Mathematics involved in assigning people to tasks when a set of different tasks must be completed	1	2	3	4
C33	Blunders and mistakes some mathematicians have made	1	2	3	4
C34	Algebra	1	2	3	4
C35	Mathematics about the age of the universe	1	2	3	4
C36	Mathematics involved in working out the best arrangement for planting seeds	1	2	3	4
C37	Mathematics to determine the number of fish in a lake, river or a certain section of the sea	1	2	3	4
C38	Mathematics linked to music from the United States, Britain and other such countries	1	2	3	4
C39	Mathematics that air traffic controllers use for sending off and landing planes	1	2	3	4
C40	Mathematics linked to rave and disco dance patterns	1	2	3	4

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C41	Mathematics involved in making pension and retirement schemes	1	2	3	4
C42	Mathematics of the storage of music on CDs	1	2	3	4
C43	Mathematics linked to decorations such as the house decorations made by Ndebele women	1	2	3	4
C44	Mathematical ideas that have had a major influence in world affairs	1	2	3	4
C45	Numbers	1	2	3	4
C46	Mathematics involved in sending of messages by SMS, cellphones and e-mails	1	2	3	4
C47	Mathematics involved in working out financial plans for profit-making	1	2	3	4
C48	Mathematics involved in my favourite sport	1	2	3	4
C49	Mathematics involved in dispatching a helicopter for rescuing people	1	2	3	4
C50	Mathematics used to work out the repayments (instalments) for things bought on credit	1	2	3	4
C51	How to predict the sex of a baby	1	2	3	4
C52	How mathematics can be used by setting up a physical training programme, and measure fitness	1	2	3	4
C53	Strange results and paradoxes in Mathematics	1	2	3	4
C54	Mathematics to monitor the growth of a baby in the first period of life	1	2	3	4
C55	Mathematics that entertain and surprise us.	1	2	3	4
C56	Mathematics to describe facts about diminishing rain forest and growing deserts	1	2	3	4
C57	How mathematics can be used in planning a journey	1	2	3	4
C58	How mathematics can be used in sport competitions like ski jumping, athletics, aerobic, swimming, gymnastics and soccer	1	2	3	4

*Julie and Holtman*

C59	Mathematics to describe movement of big groups of people in situations such as emigration and refugees fleeing from their countries	1	2	3	4
C60	Mathematics involved in determining levels of pollution	1	2	3	4
C61	Mathematics involved in military matters	1	2	3	4

C62 Please write down 3 issues that you are very interested in learning about the use of mathematics in these issues.

(a) \_\_\_\_\_

(b) \_\_\_\_\_

(c) \_\_\_\_\_

Why are you interested in these issues?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

C63 Are you interested in learning something on mathematics that arises while you are learning other school subjects?

YES

NO

Why? \_\_\_\_\_

Why not? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

*The Relevance of School Mathematics Education (ROSME)*

C64 Are you interested in learning something on mathematics related to issues that have been in the newspapers or radio or TV recently?

YES

NO

Why? \_\_\_\_\_

Why not? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

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C65 Make a sketch or drawing of a mathematician working.



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